Surface properties of concrete and criteria for adhesion of repair systems

Luc COURARD, Université de Liège, Belgique

Andrzej GARBACZ and Tomek PIOTROWSKI, Warsaw University of Technology, Poland

Jakob SUSTERCIC, IRMA, Slovenia

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Degradation of concrete

Kiewit (B) (photo DvGemert)

Québec (Canada)

Hognoul (B)

Sherbrooke (Canada)

… and repair of concrete

Chicago (USA)

Skayszewski Park (PL)

Sclessin (B)

Sclessin (B)

Overview

Pathologies of concrete

Parameters affecting adhesion

Theory and principles of repair

Investigations and practice

Conclusions

Fort Loncin

Pathologies of concrete

Main causes and defects

Pathologies of concrete

Effects

lixiviation

settlements

deflection

abrasion

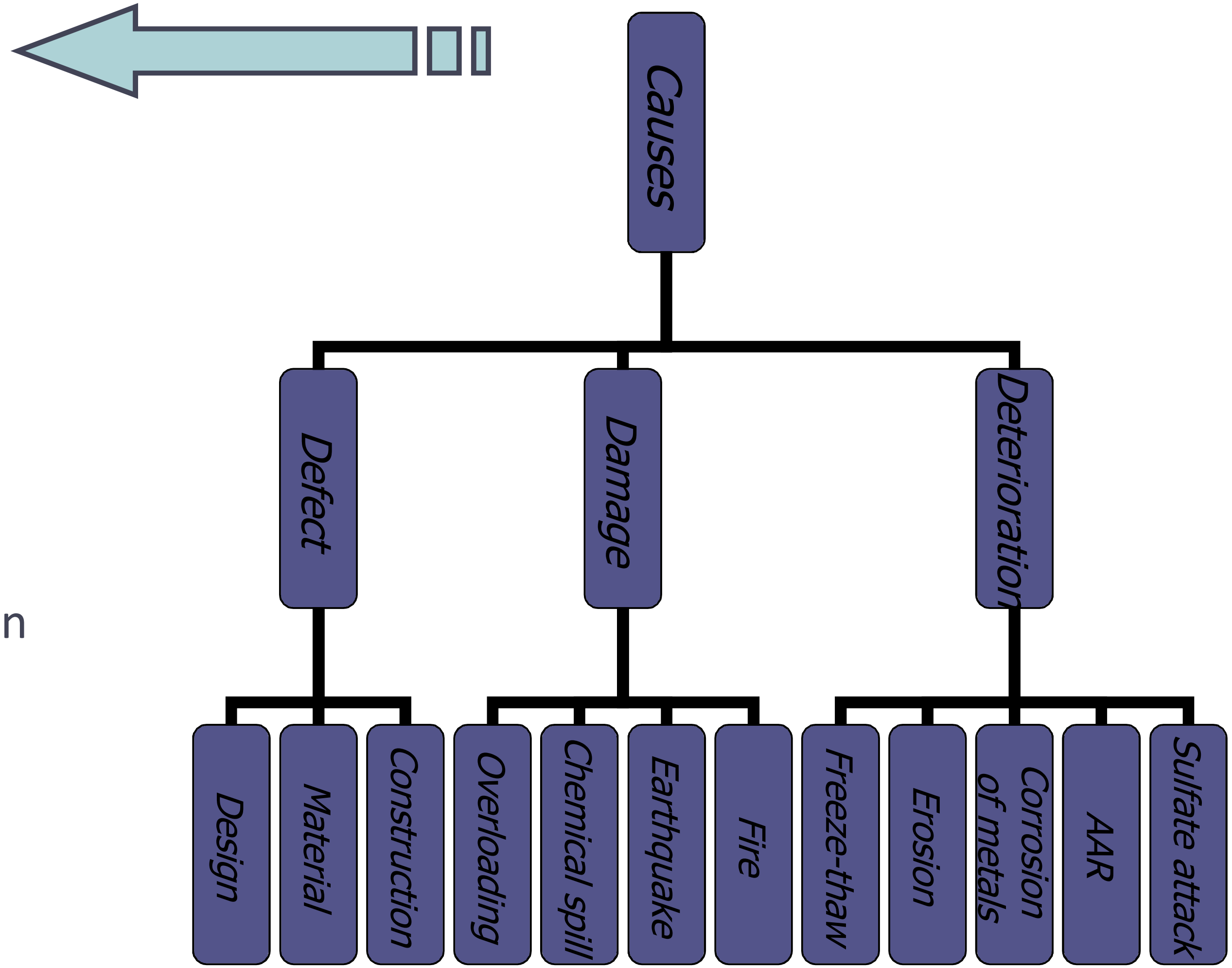
spalling

desintegration

cracking

delamination

scalling



Pathologies of concrete

Main effects

- spalling
- desintegration
- cracking

First cause: **water**

Secondary causes

- steel bar corrosion
- desintegration mechanisms
- humidity effects
- design and casting errors

spalling, Saint-Vincent church, Liège

cracking (Photo B. Chmielevska)

desintegration, city of Liège

Construction defects

Steel cover

Compaction

Segregation

Plastic shrinkage and settlement

Slope (water flowing and exit)

construction joints

segregation

plastic shrinkage

plastic settlement

Structural defects

Differential settlement

Thermal dilatation

Overloading (snow, earthquake)

Water ingress

water ingress

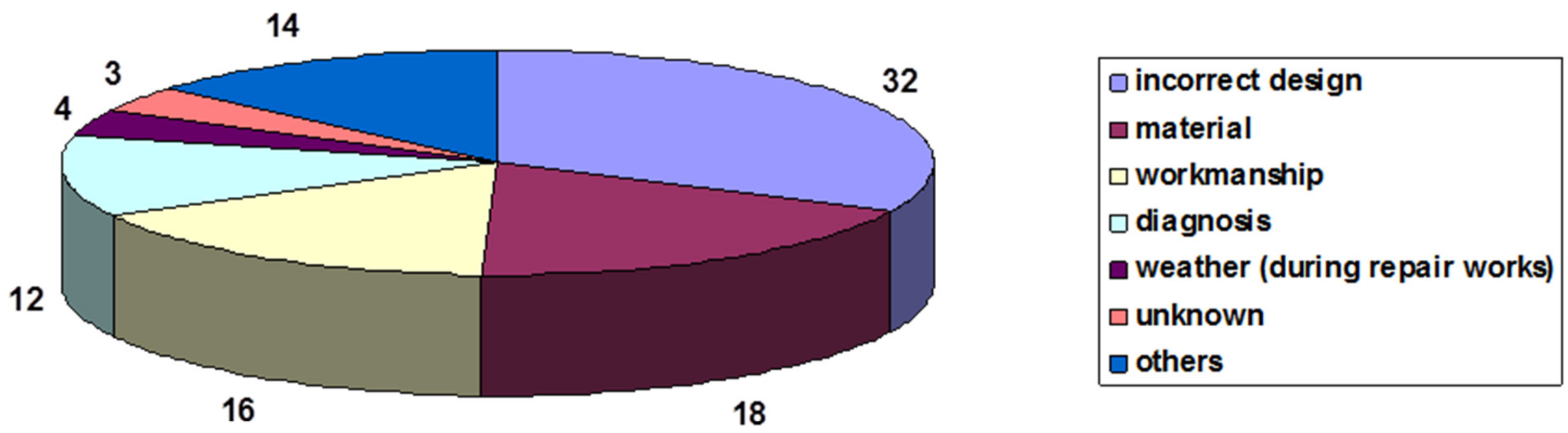
vertical cracking in a pile

crack in the central part of the lintel

Parameters influencing adhesion

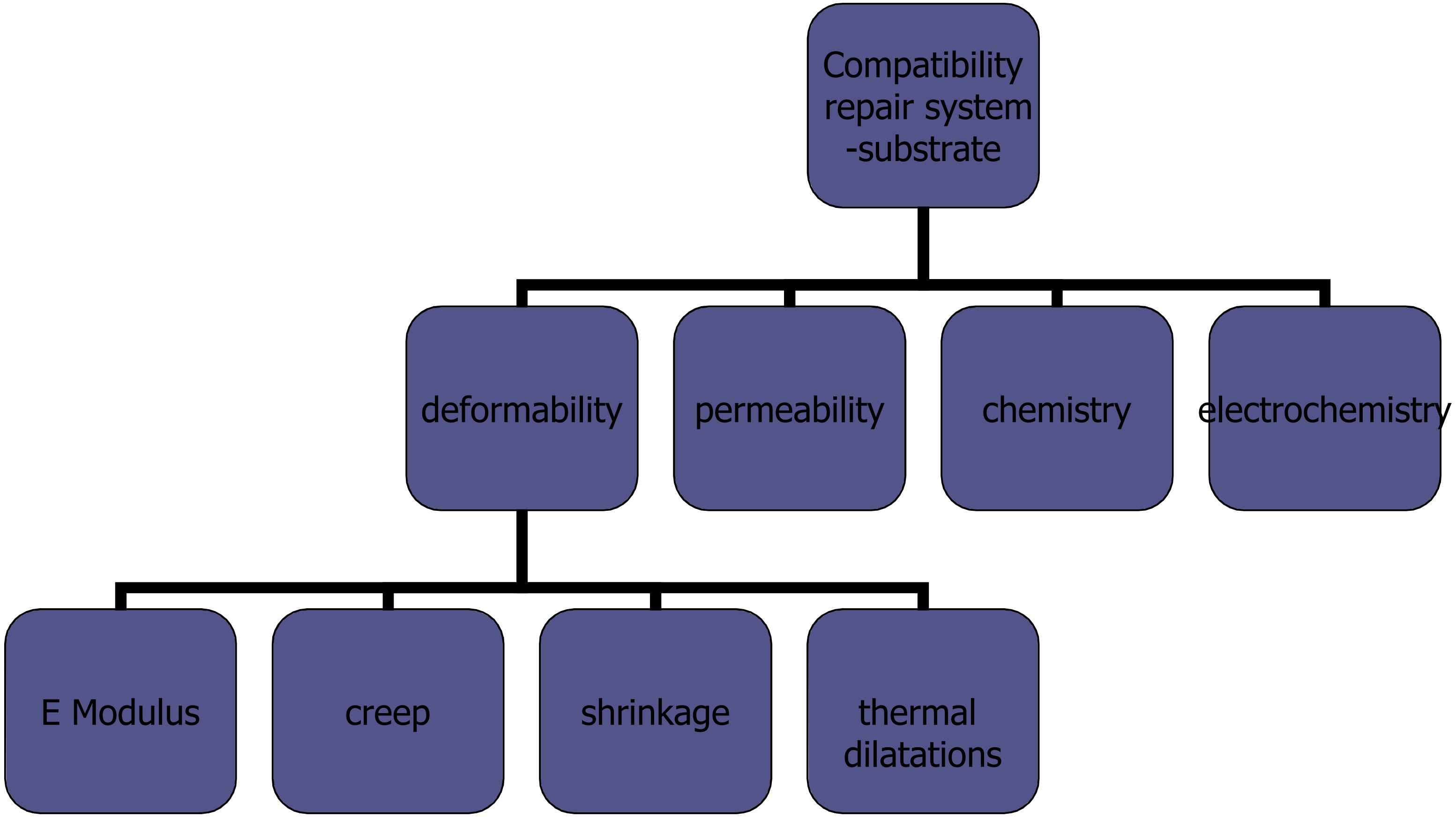
Analysis

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



50% failure after 5 years !

Main parameters affecting the quality of repair (Bissonnette, 2004)



Courard, L. and Bissonnette, B. (2007) Compatibility performance as a fundamental requirement for the repair of concrete structures with Self-Compacting Repair Mortars (keynote lecture). L. Courard and B. Bissonnette. In: 5th International RILEM Symposium on Self-Compacting Concrete, Proceedings PRO 54 (Eds. G. De Schutter and V. Boel, Rilem Publications), Gent, Belgium, 667-675.

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

Theory and principles

Adhesion requirements

Adhesion and repair

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)

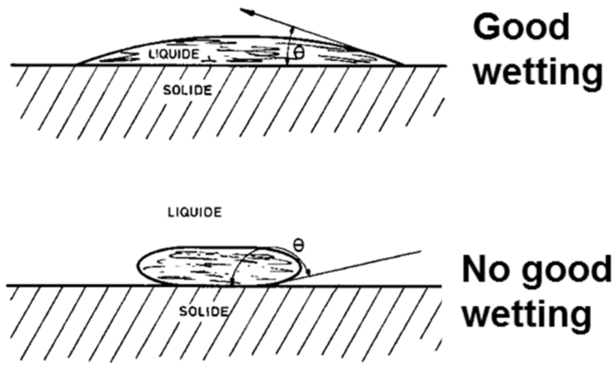
… the heterogeneity of the components in a composite repaired structure requires an **understanding of the interaction** of the existing materials and the repair materials …

(Vaysburd et al., 2004)

Principles of adhesion

Adhesion

- **Specific adhesion**
  - **Physico-chemical interactions**
  - **Thermodynamic approach**
  - **Chemical bonding**
- **Mechanical adhesion**



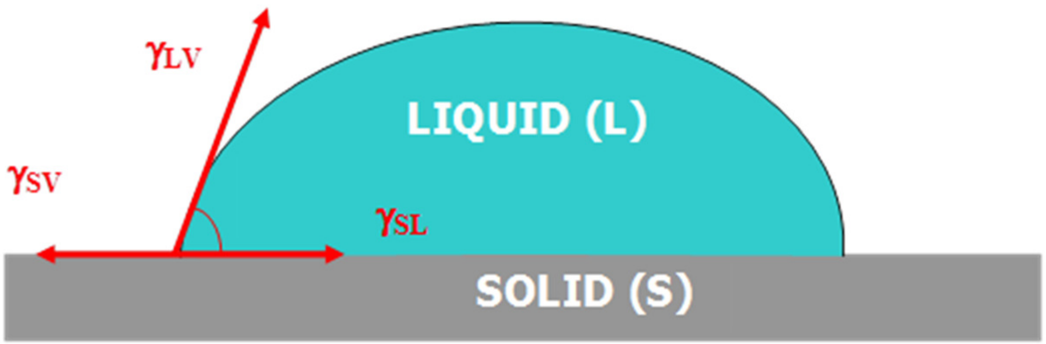
Condition 1 : spreading and wettability

Condition 2 : physico-chemical interactions

Condition 3 : mechanical interlocking

Principles of adhesion

Condition 1 : spreading



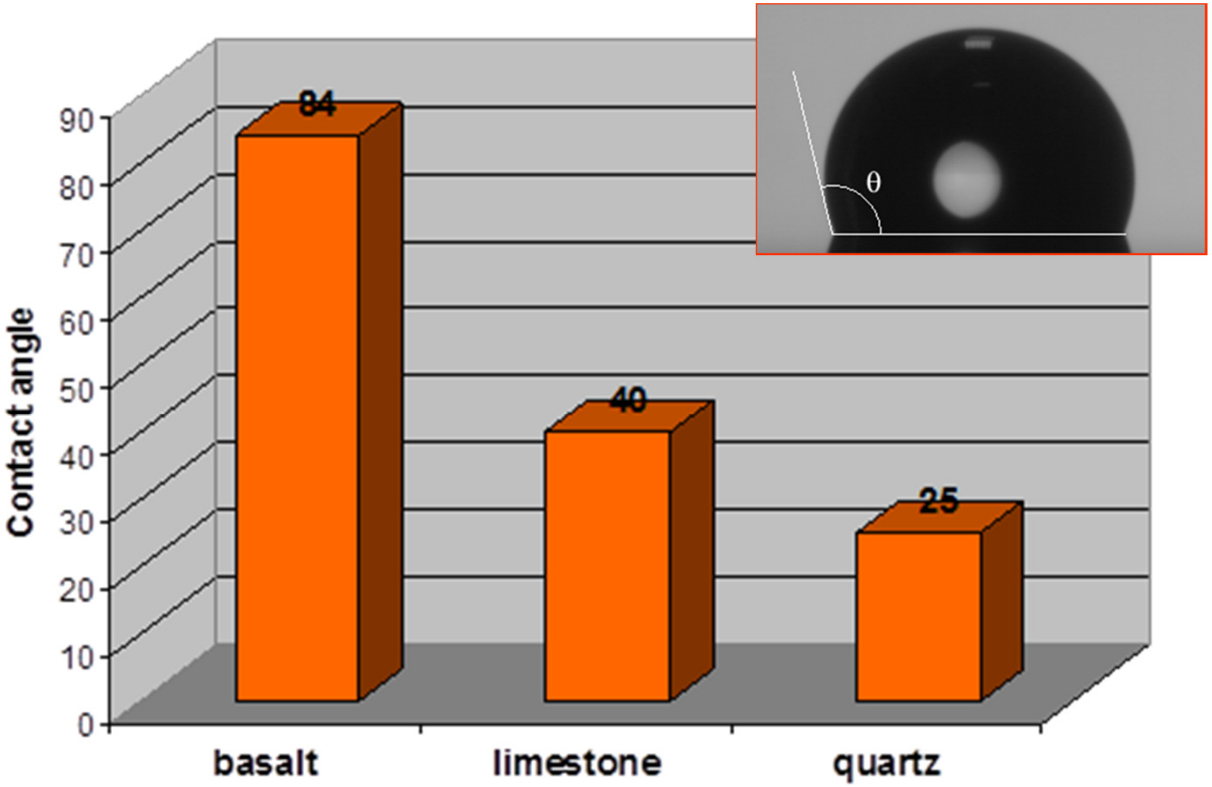
$$\gamma_{SV} = \gamma_{SL} + \gamma_{LV} \cos \theta$$

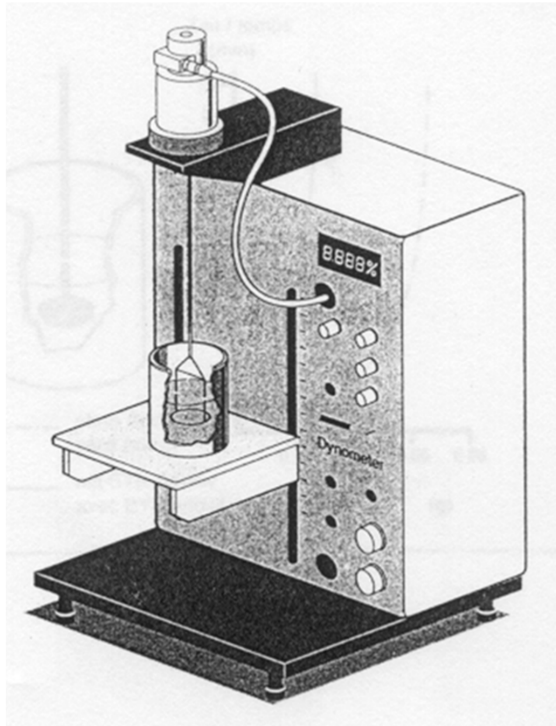
Better wettability of the solid by the liquid if the contact angle is low

Courard, L. (2002) Evaluation of thermodynamic properties of concrete substrates and cement slurries modified with admixtures. Mater. Struct., 35, 149-155.

Principles of adhesion

Surface energy of solids and liquids

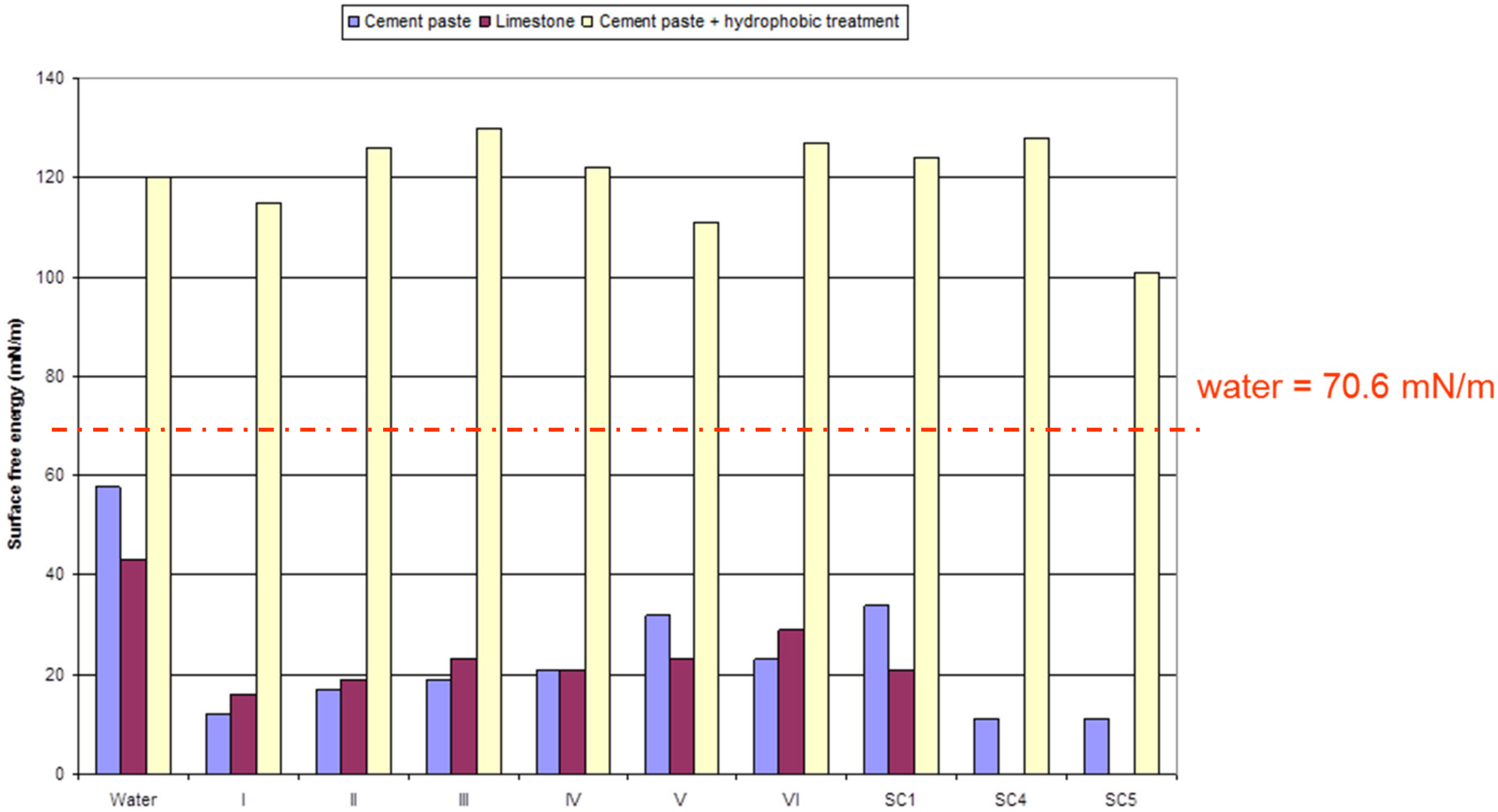




(Fiebrich, 1994)

Principles of adhesion

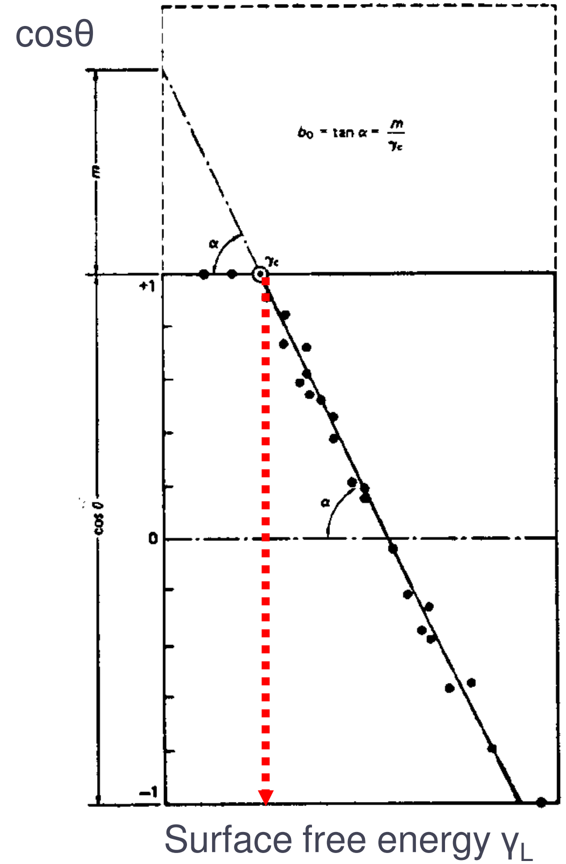
Contact angle of modified cement slurries on 3 types of substrates



Principles of adhesion

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
PolyVinl Chloride (PVC)	39
PolyEthylen (PE)	31
PolyTetraFluorEthylen (PTFE)	18.5



Principles of adhesion

Selection criteria

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

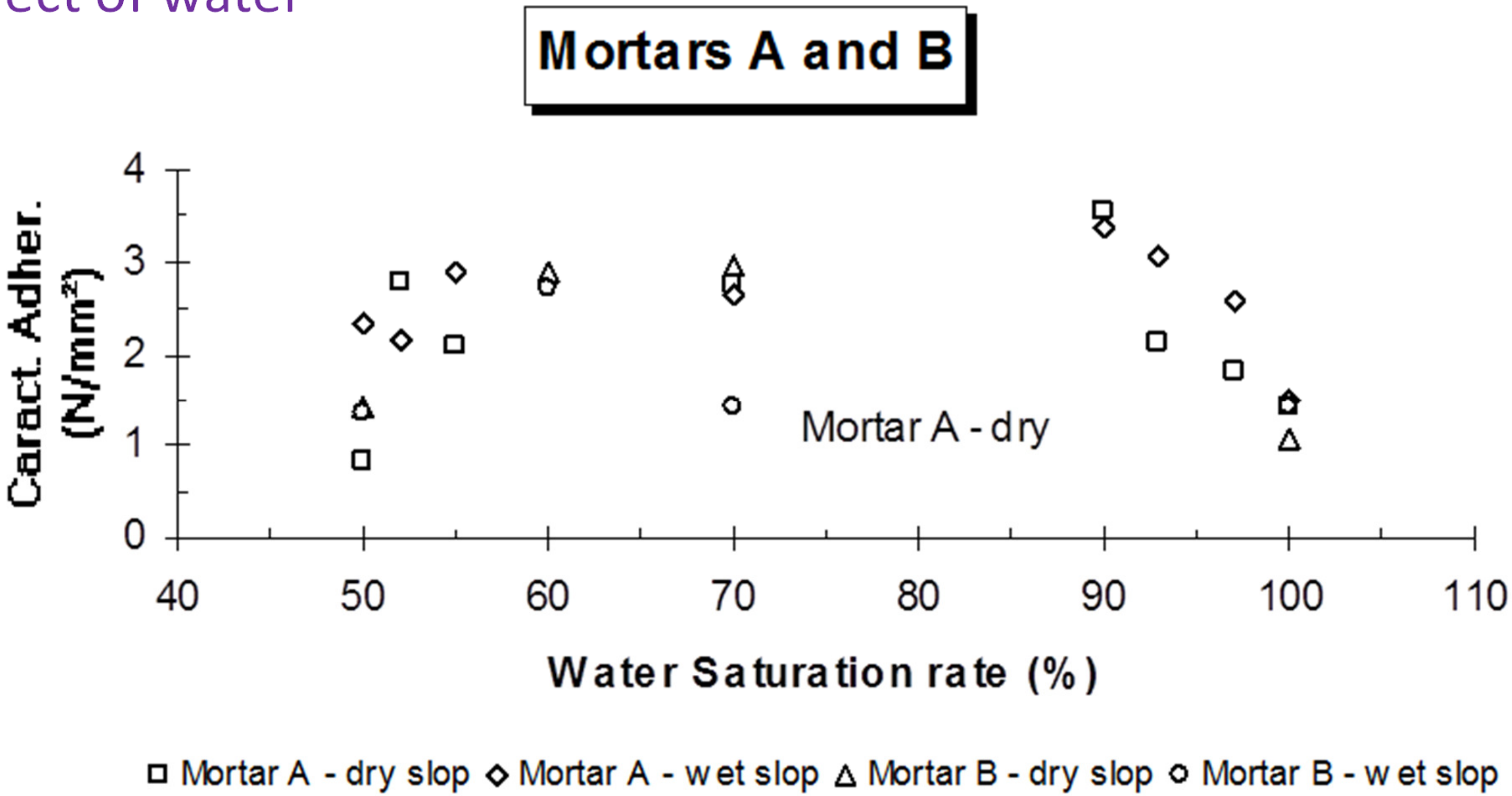
- γ_S maximum: to avoid dust, oil or to promote surface treatment
- γ_{SL} minimum: adhesive performances

BUT: necessary but not sufficient

- kinetics of contact: surface roughness and viscosity of repair system
- mechanical aspects of adhesion

Principles of adhesion

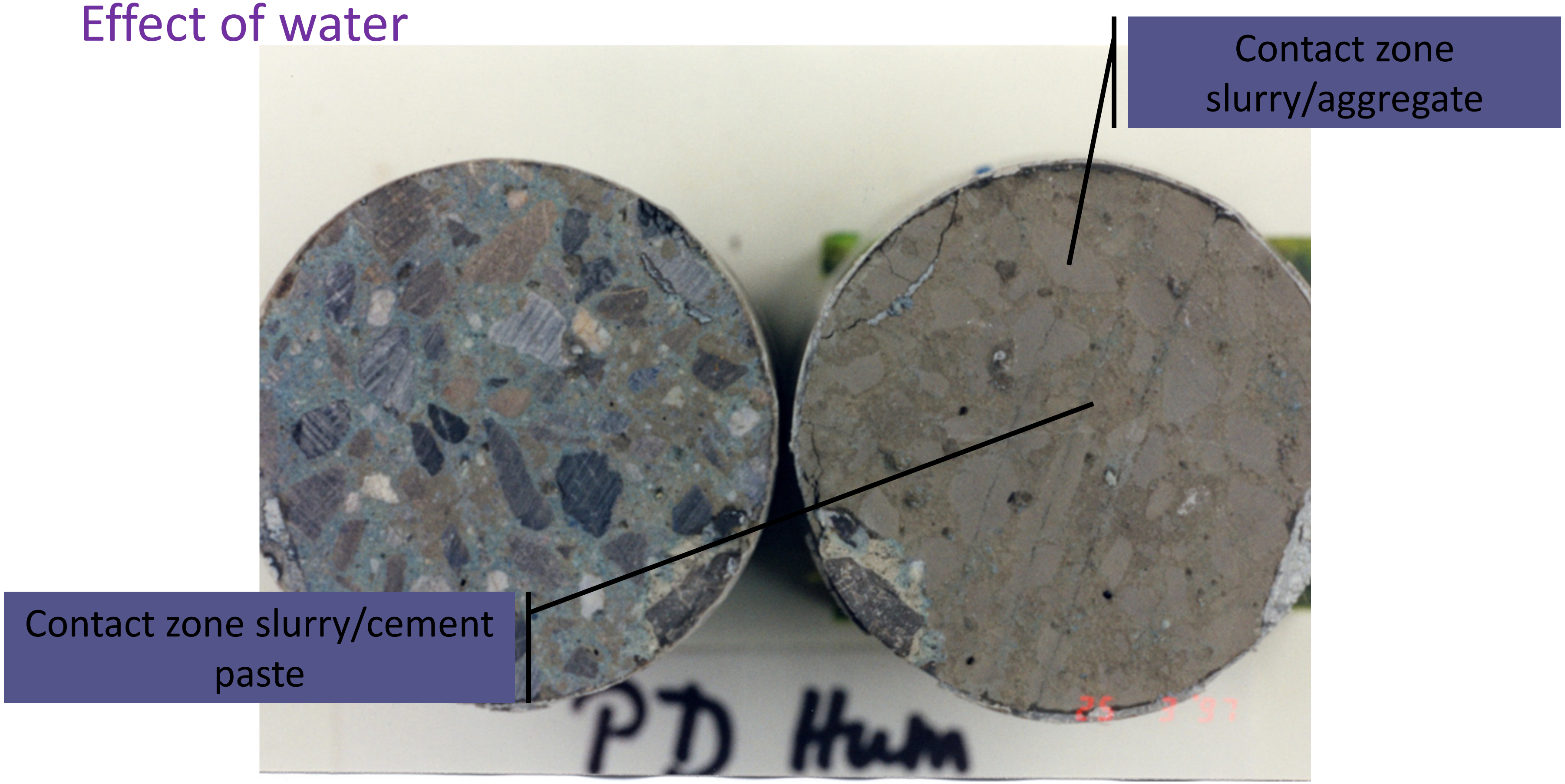
Effect of water



Influence of the operating conditions and humidity on adherence of repair mortars. L. Courard, R. Degeimbre, A. Darimont, J. Wiertz. In: ICPIC, VIIIth International Congress on Polymers in Concrete (Ed. D. van Gemert, KULeuven en KVIV), Oostende (1995), 585-590.

Principles of adhesion

Effect of water



Analysis of the resistance to water of the interface between concrete and repairing systems: experimental approach. L. Courard, R. Degeimbre, J. Wiertz, M. Van de Put. in: CONSEC '98, 2nd International Conference on Concrete under Severe Conditions (Eds. O.E. Gjorv, K. Sakai and N. Banthia, E&FN Spon), Tromso, Norway (1998), 988-996.

Principles of adhesion

Effect of water

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

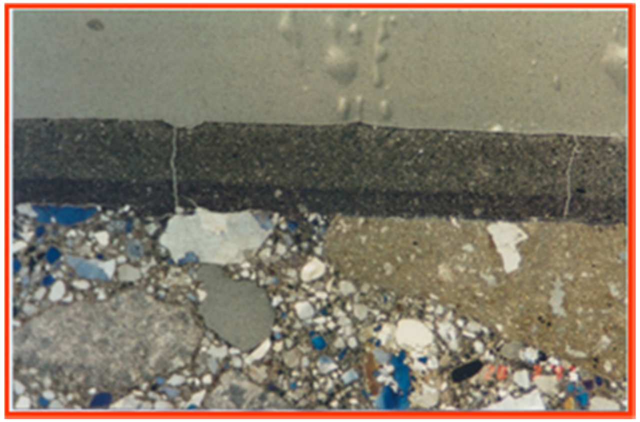
A = air **L = water**

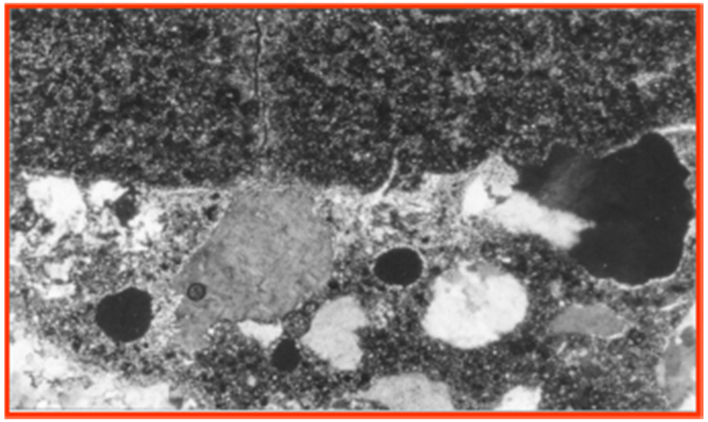
Interface	W_A (mJ/m²)	W_{AL} (mJ/m²)
Mortar/concrete	87.8	No sense
Acrylic/Concrete	74.1	22.7
Acrylic/Acrylic	80.4	53.7
Acrylic/Hydrophobic treatment	52.2	66.7
Epoxy/Concrete	79.6	21.8
Epoxy/Epoxy	92.4	53
Epoxy/Hydrophobic treatment	56	42.2

Loss of adhesion when water

Principles of adhesion

Effect of micro roughness



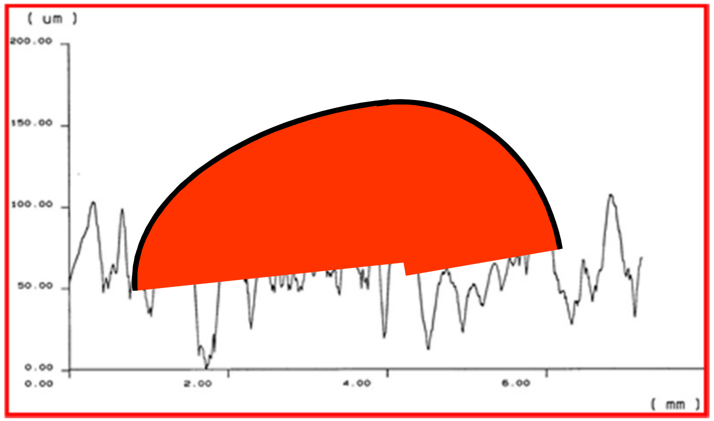


If $\theta_l < 90°$ on smooth surface

$\Rightarrow \theta_r \downarrow$ on rough surface

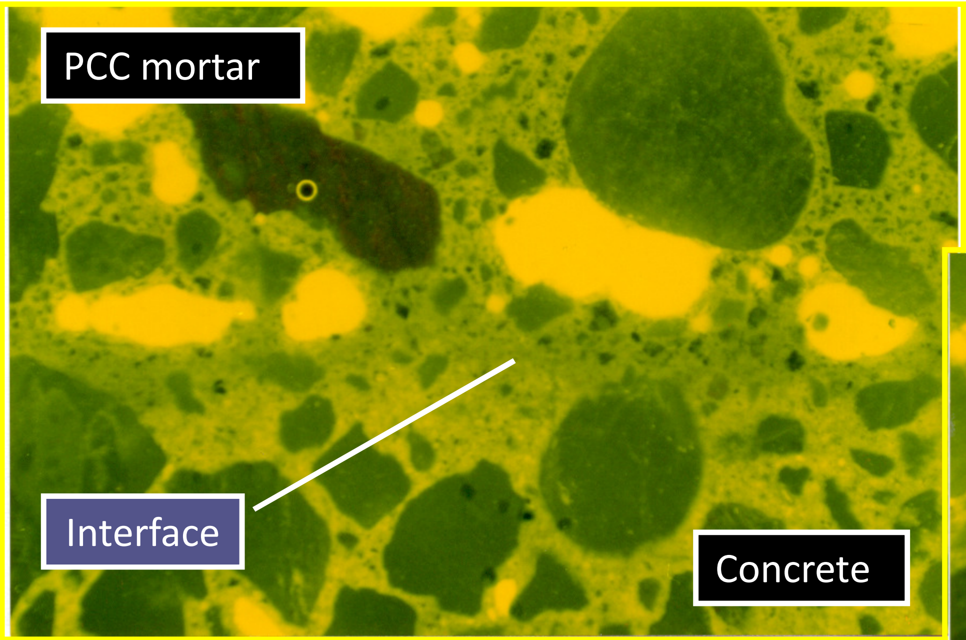
Coefficient of Wenzel r_f

$\cos \theta_r = r_f \cos \theta_s$



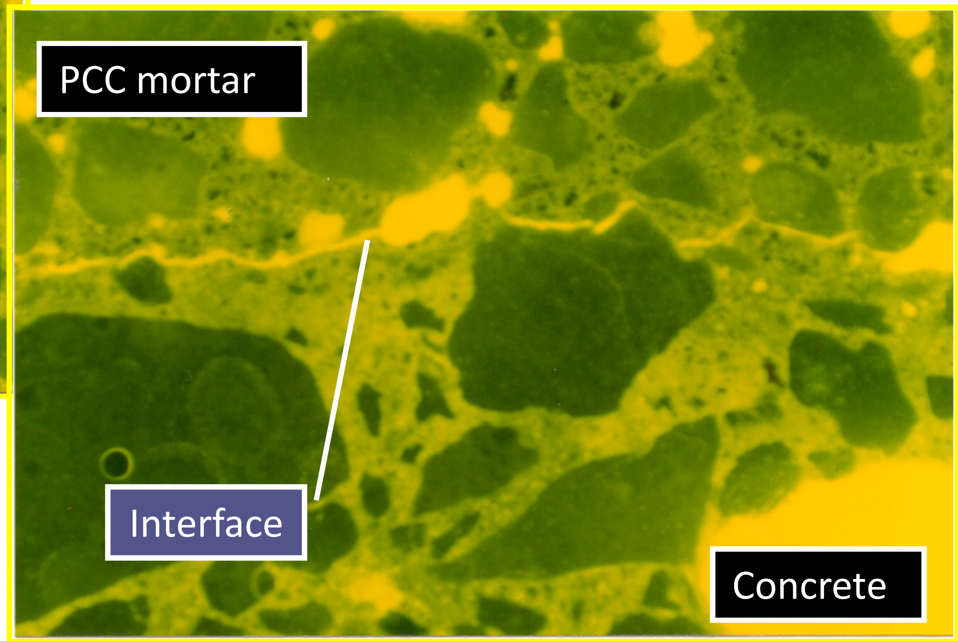
Principles of adhesion

Effect of workmanship



Application

Worker	Mean adhesion (N/mm^2)
A	1.60
B	2.60

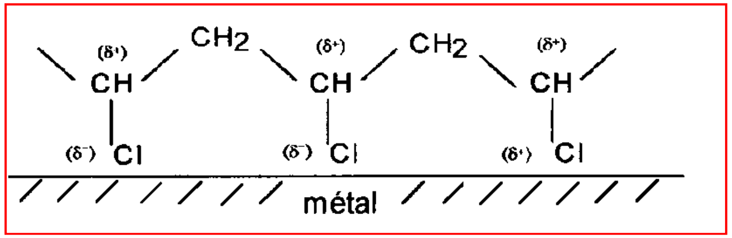


Pressure and smoothing

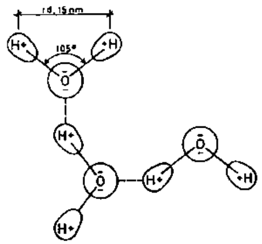
Principles of adhesion

Condition 2 : physico-chemical interactions

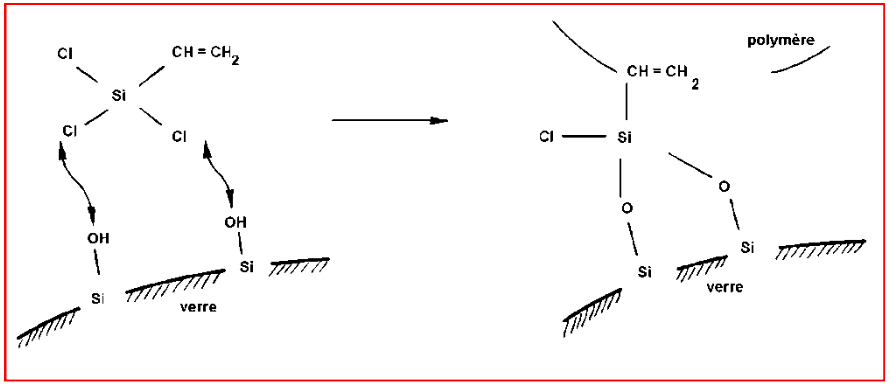
Van der Waals



Hydrogen bonds

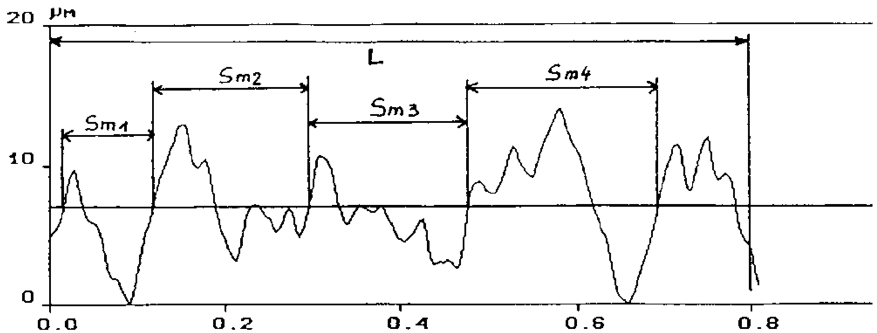


Chemical bonds

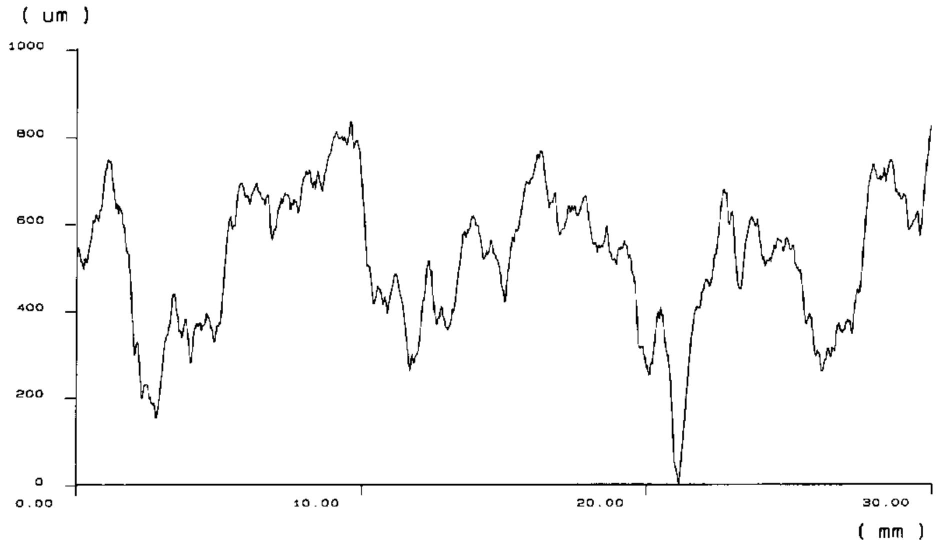


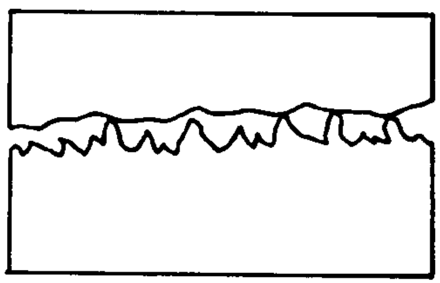
Principles of adhesion

Condition 3 : mechanical interlocking

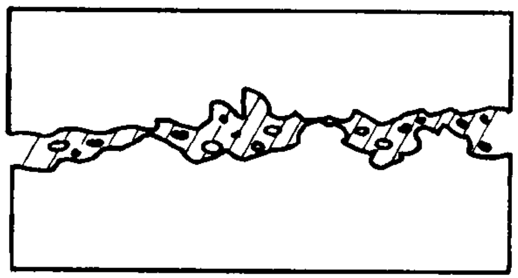


Definition of the profile





A



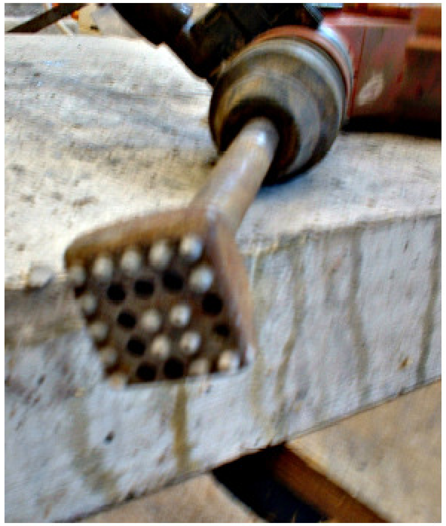
B

Investigations and practice

Surface preparation of concrete

Surface preparation: evaluation

polishing



scabbling

Surface preparation: effects

water-jetting

sandblasting

Surface preparation: effects

scarification

jack hammer

Surface preparation: evaluation

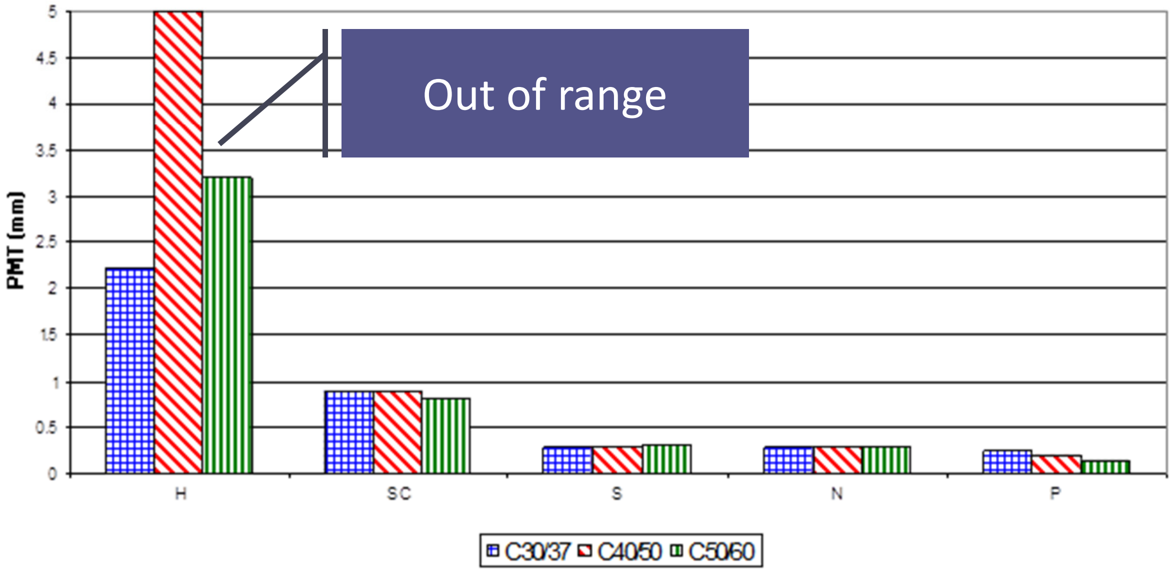
Surface Rough Index SRI = $4V/\pi D^2$

H = water-jetting

SC = scabbling

S = sandblasting

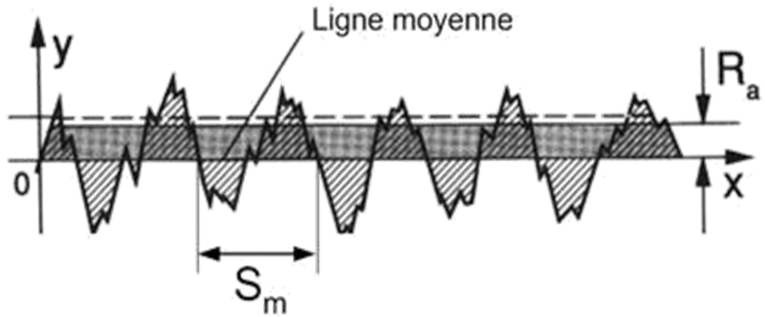
P = polishing



Surface preparation: evaluation

Based on specific approach [Courard,1999]

Parameters	*Definition*
X_t	*total height of the profile*
X_v	*maximum depth of the profile (holes)*
X_p	*maximum height of the profile (peaks)*
X_a	*arithmetic mean of the deviation of the profile from the mean line*
X_q	*quadratic mean of the deviation of the profile from the mean line*
S_k	*skewness of surface height distribution*
S_m	*mean spacing between profile peaks at the mean line, measured over the assessment length*
C_F, C_L, C_R	*Bearing ratio parameters*



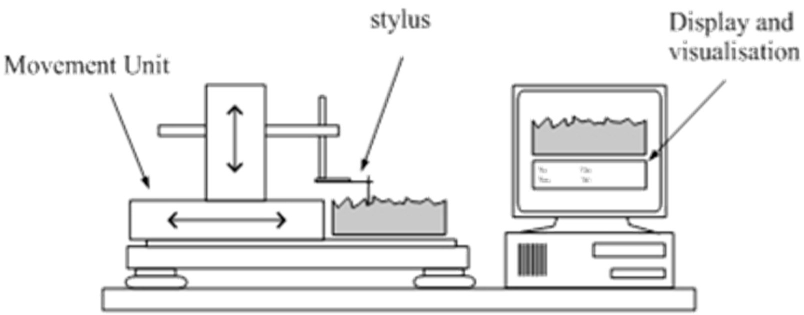
Courard, L. and Nélis, M. (2003), Surface analysis of mineral substrates for repair works: roughness evaluation by profilometry and surfometry analysis. Mag. Concrete Res., 55(4), 355-366.

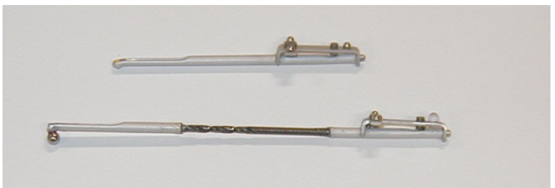
Surface preparation: evaluation

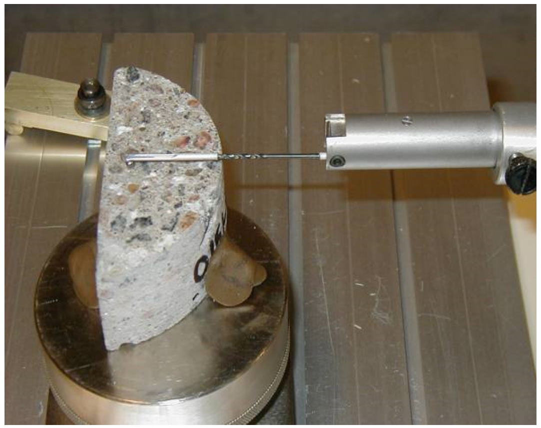
Principle

A stylus walks along the surface. His vertical movement provides profile’s description

Precision depends on stylus dimensions and path length between two measurements

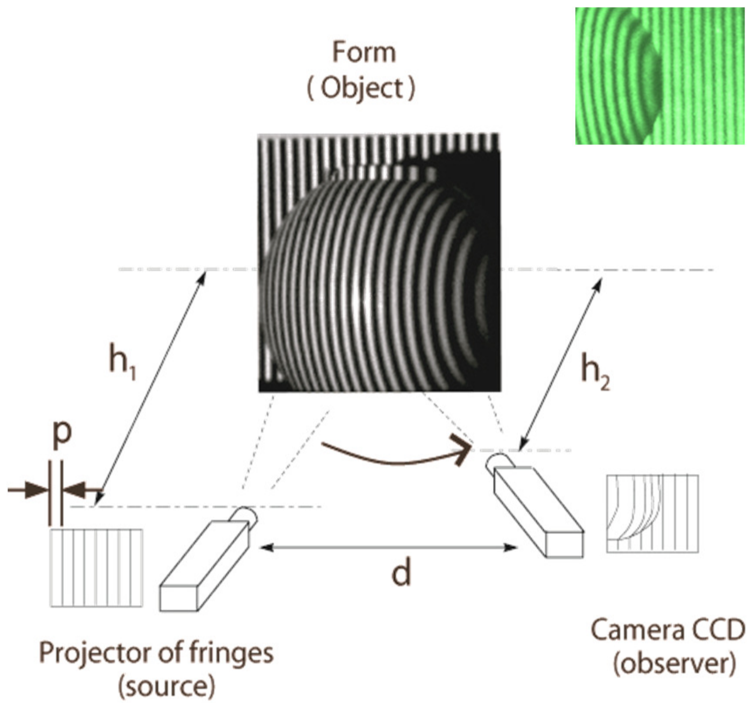


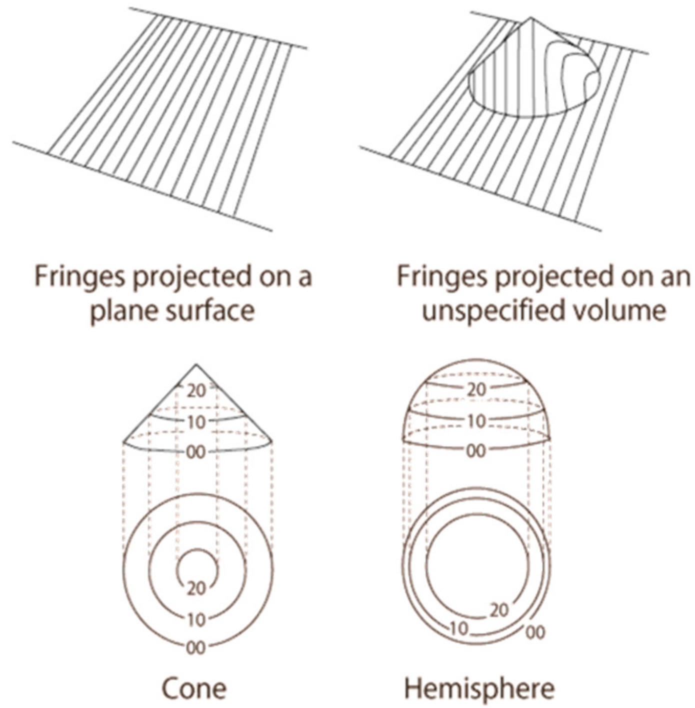




Surface preparation: evaluation

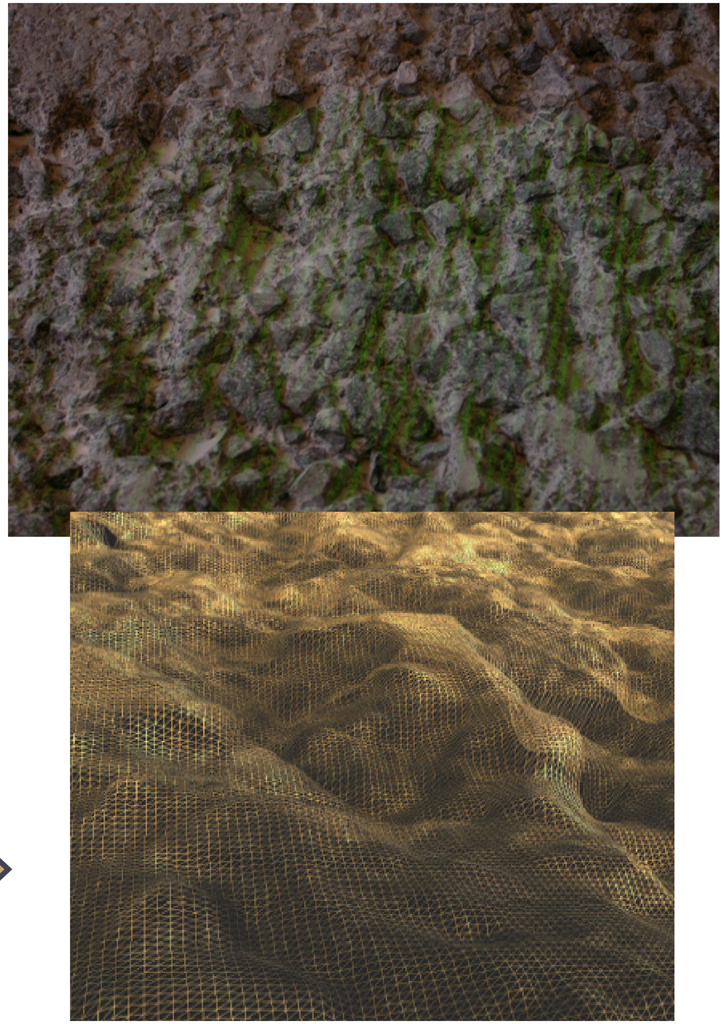
Deformation of parallel and periodic fringes (level line)

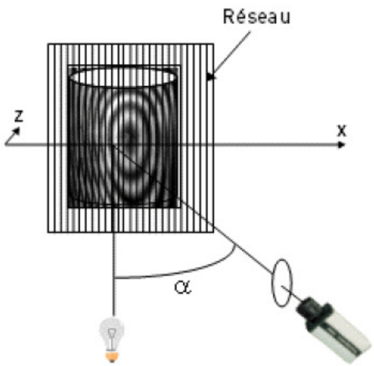




Relation between form and level line

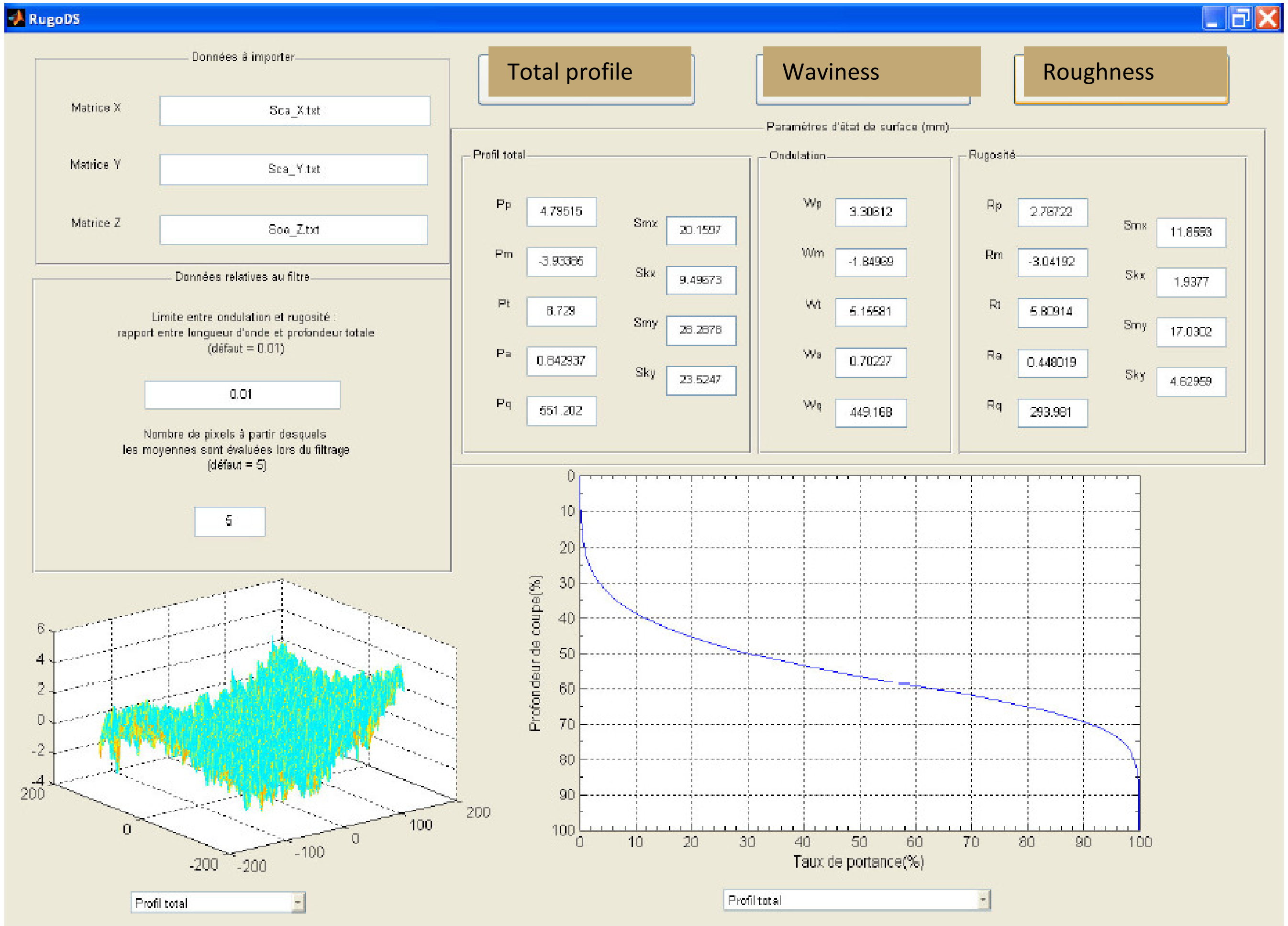
Surface preparation: evaluation



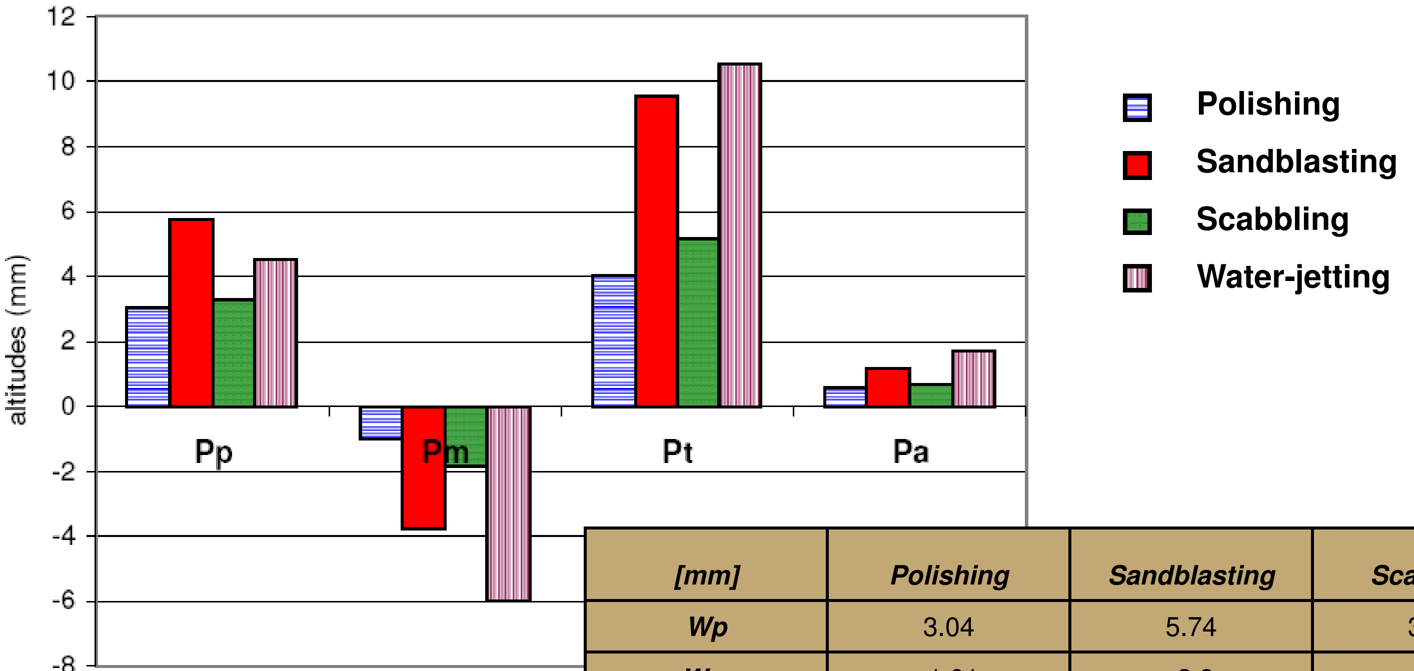


Mathematical treatment

Surface preparation: evaluation



Surface preparation: evaluation



[mm]	*Polishing*	*Sandblasting*	*Scabbling*	*Water-jetting*
Wp	3.04	5.74	3.31	4.52
Wm	-1.01	-3.8	-1.85	-6.01
Wt	4.05	9.54	5.16	10.54
Wa	0.57	1.18	0.7	1.71
Wq	371.69	805.2	449.17	1109.49
Cr	0.22	1.14	0.39	2.95
Cf	0.75	1.38	1.11	3.11
Cl	1.62	3.82	1.65	2.32

Surface preparation: evaluation

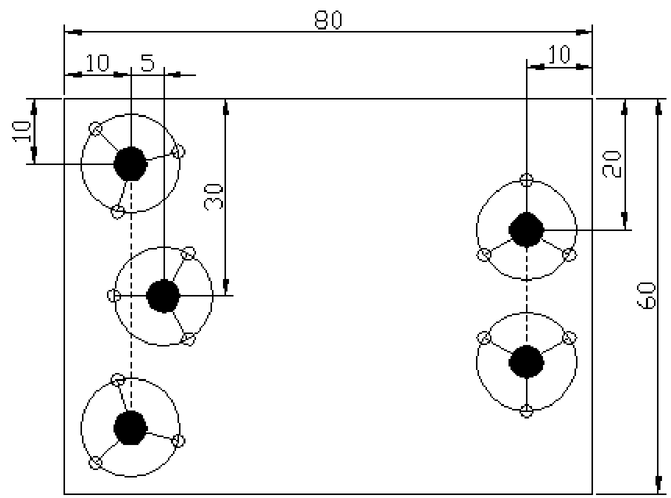
Pull-off equipment

Diameter of the steel dolly: 50-mm;

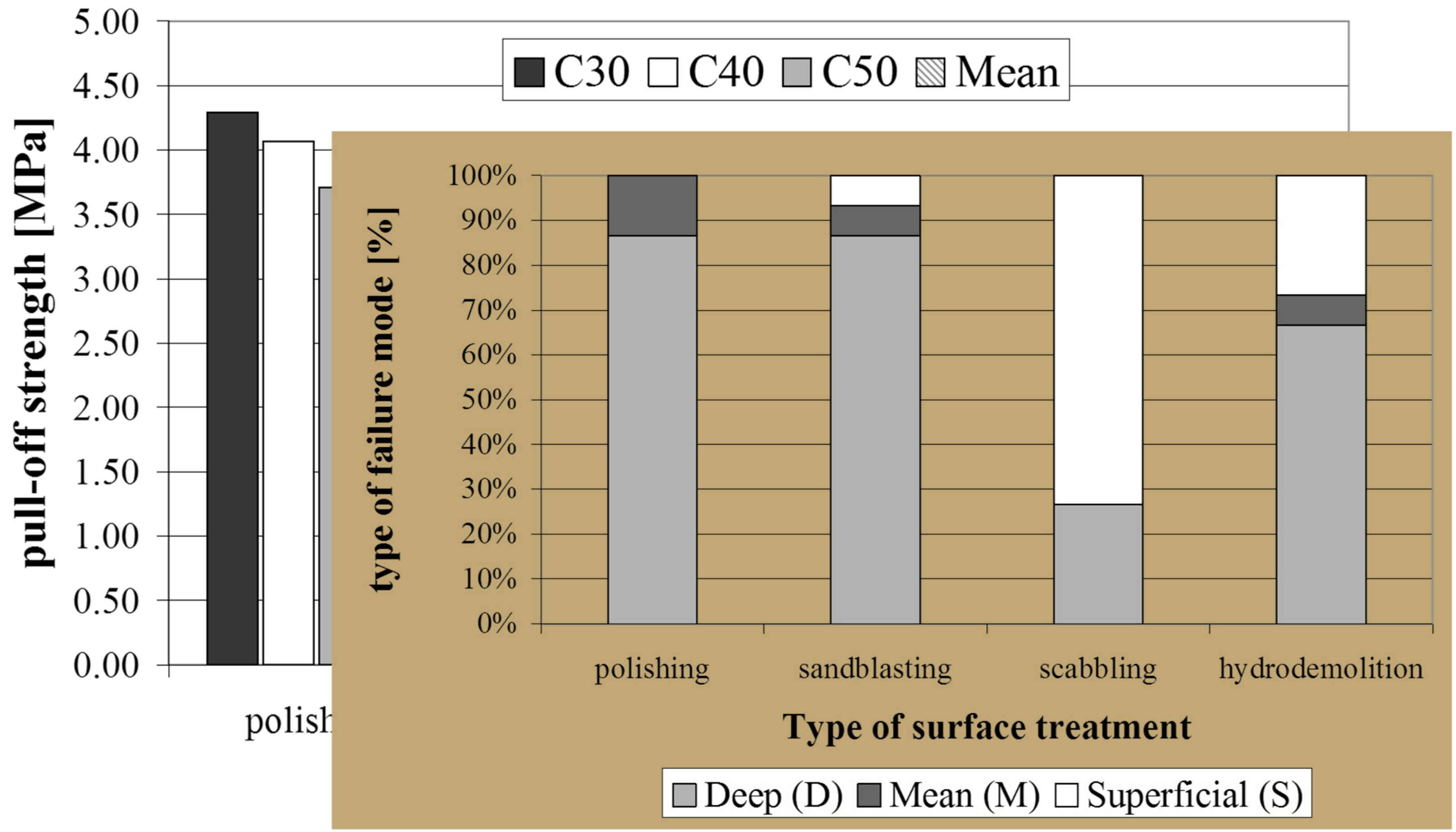
Depth of coring: 15-mm;

Number of tests: 5;

Loading rate: 0.05 MPa/s



Surface preparation: evaluation

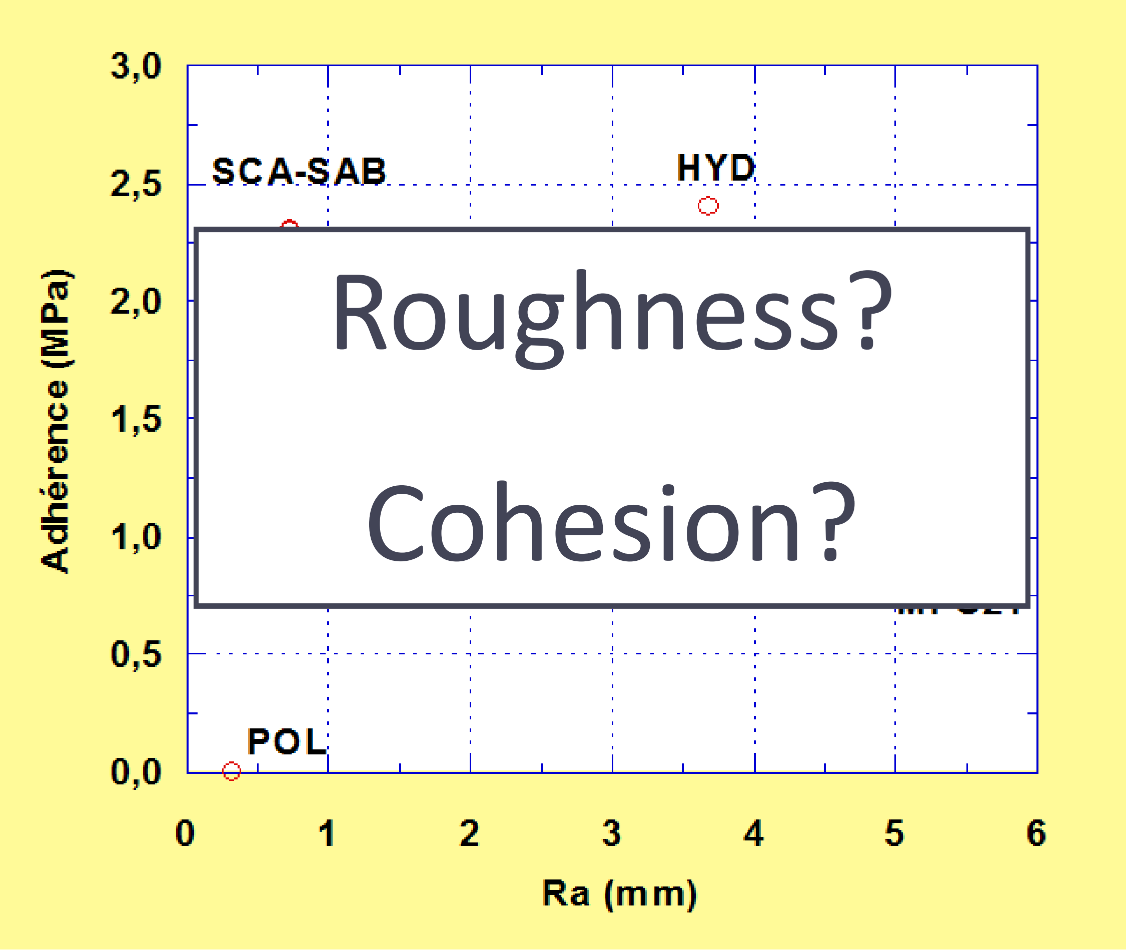


Surface preparation: evaluation

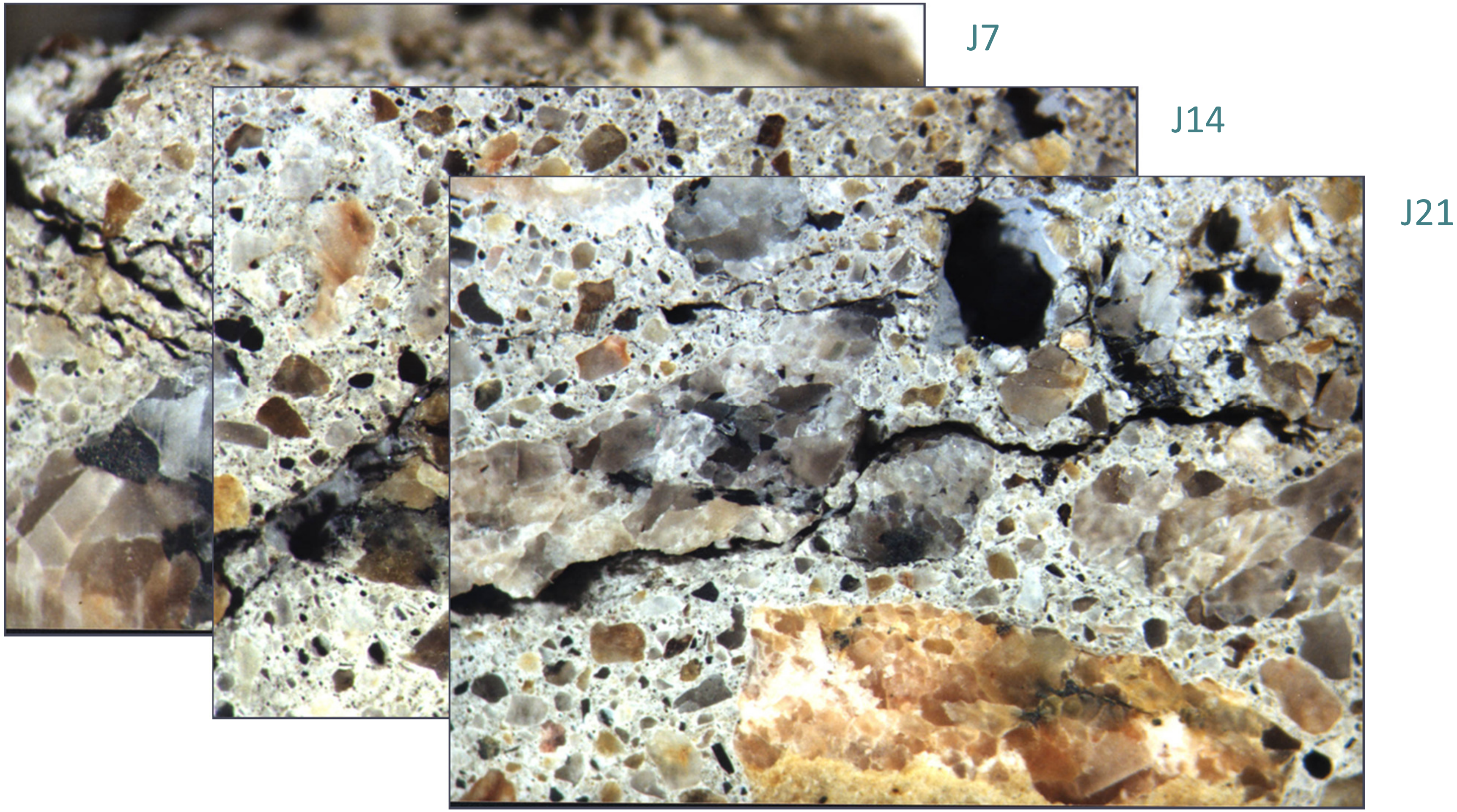
Treatment type	Mean value [MPa] (coefficient of variation in %)	
	Repair mortar with bond coat	Repair mortar without bond coat
NT	1.92 (23.4)	2.28 (17.1)
GR	1.82 (15.9)	1.16 (50.9)
SB	1.93 (11.4)	1.82 (32.4)
SHB20	1.68 (18.5)	0.78 (39.7)
SHB35	1.94 (11.3)	1.25 (28.8)
SHB45	1.96 (32.7)	0.83 (25.3)
HMIL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

Characterization of concrete surface roughness and its relation to adhesion in repair systems. A. Garbacz, L. Courard and K. Kostana. Mater. Charact., 56 (2006) 281-289

Why and how?

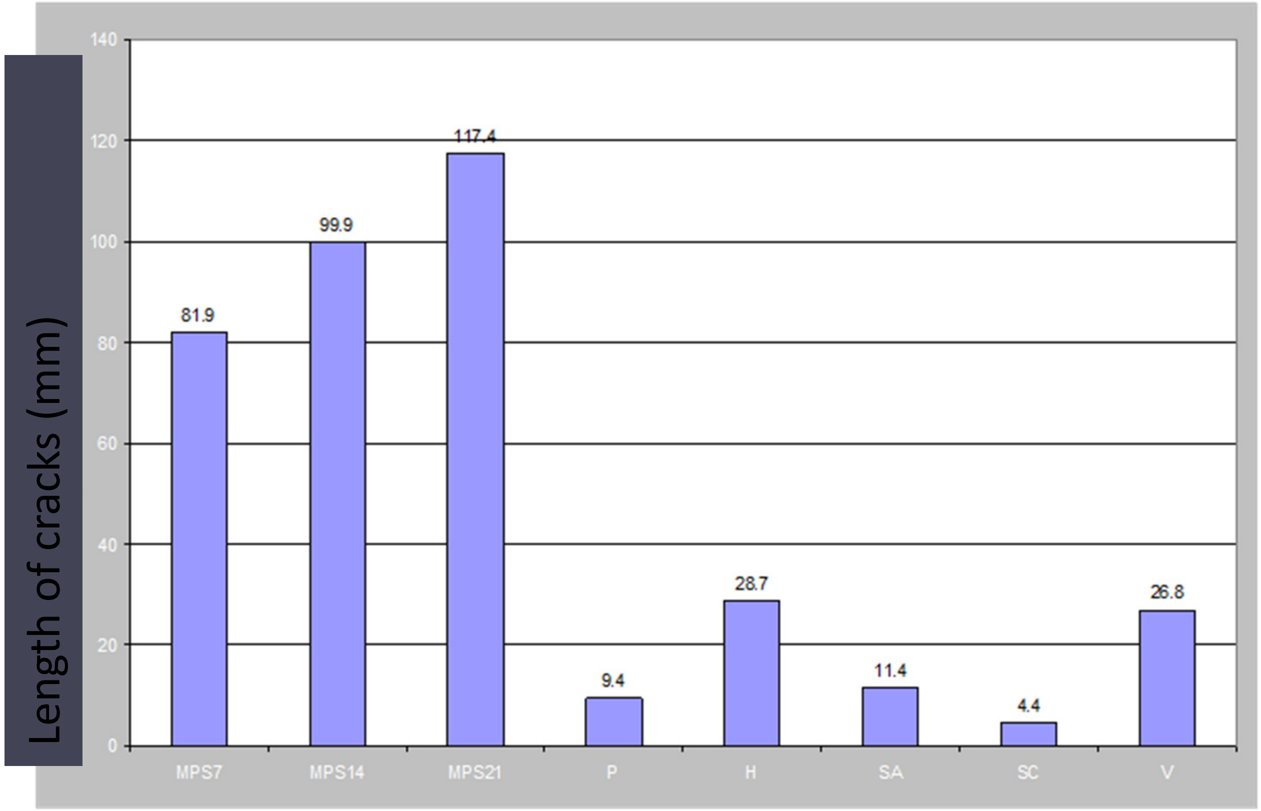

3,0
2,5
2,0
1,5
1,0
0,5
0,0
Adhérence (MPa)
SCA-SAB
HYD
POL
0
1
2
3
4
5
6
Ra (mm)
Roughness?
Cohesion?

Surface preparation: evaluation



Surface preparation: evaluation

Total length of cracks



Concrete removal techniques: influence on residual cracking and bond strength. B. Bissonnette, L. Courard, A. Vaysburd and N. Bélair. Concrete International, 28(12) 2006, 49-55

Conclusions and prospects

Recommendations

Conclusions and recommendations

Needs for adhesion and quality of repair

- Induce minimum roughness
- Avoid micro-cracking
- Select appropriate surface preparation
- Remove laitance layer and clean the surface
- Remove free water
- Prefer SSD surface for Repair Cementitious Mortars
- Impose minimum cohesion of the superficial zone of concrete ≥ 1.5MPa

Aknowledgments

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Falemnderit
Merci
Takk
Hvala
Dziękuję
Thank you
Dank u
Grazie
Danke
Gratias
Arigato
Efkaristos