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SURFACE CHARACTERIZATION METHODS FOR QUALITY CONTROL OF REPAIRS

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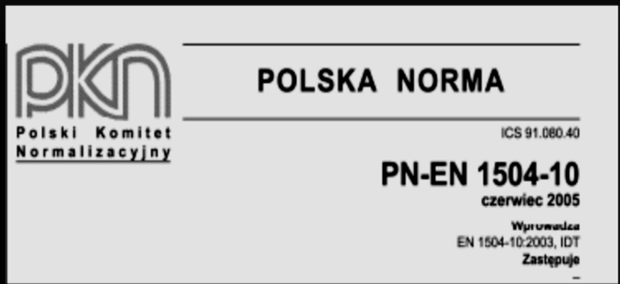
REPAIR EFFICIENCY EVALUATION


POLSKA NORMA

Polski Komitet Normalizacyjny

ICS 91.080.40

PN-EN 1504-10

czerwiec 2005

Wprowadza

EN 1504-10:2003, IDT

Zastępuje

- bond strength

  &

- bond quality

… should be evaluated

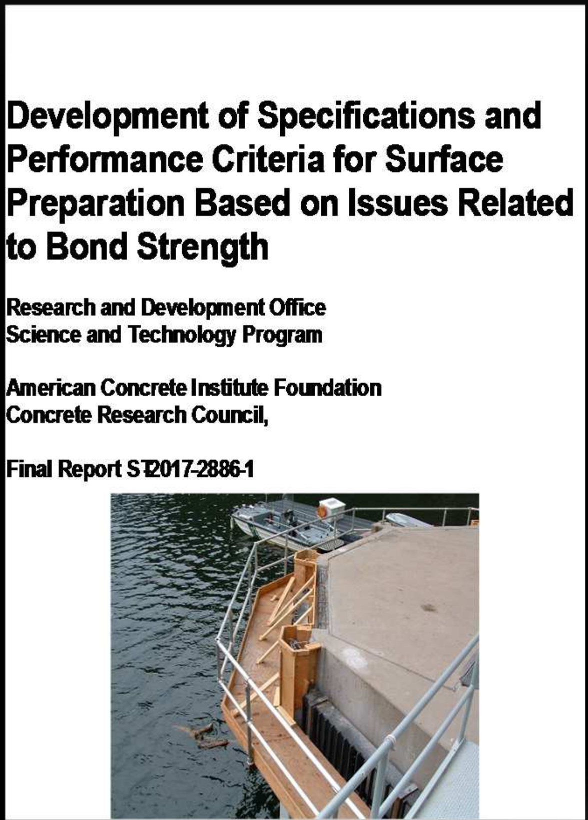
FACTORS AFFECTING BOND BETWEEN CONCRETE SUBSTRATE AND REPAIR MATERIAL

Factors	Importance		
	1	2	3
Substrate characteristics			
Substrate properties	X		
Microcracking			X
Laitance			X
Roughness	X		
Cleanliness			X
Overlay characteristics & application technique			
Pre-wetting		X	
Bonding agents	X		
Overlay properties		X	
Placement	X		
Compaction			X
Curing			X
Environmental conditions			
Time		X	
Early traffic	X		
Fatigue	X		
Environment	X		

PREPARATION TECHNIQUES *(SILFWERBRAND, 2004)*

Removal method	Principle behaviour	Depth action?	Advantages	Disadvantages
Sandblasting & shotblasting	Blasting with sand or steel balls	No	No microcracking, no dust	Not selective
Flame-cleaning	Thermal lance	No	Effective against pollutions and painting	The reinforcement may be damaged, smoke and gas development, not selective
Milling (scarifying)	Longitudinal tracks are introduced by rotating metal lamellas	Yes	Good bond if followed by water flushing	Not selective
Pneumatic (jack) hammers, hand-held or boom-mounted	Compressed-air-operated chipping	Yes	Simple use, large ones are effective	Damages reinforcement and concrete surface, poor working environment, not selective
Grinding	Grinding with rotating lamella	No	Removes uneven parts	Dust development, not selective
Explosive blasting	Controlled blasting using small, densely spaced blasting charges	Yes	Effective for large removal volumes	Difficult to limit to solely damaged concrete, not selective
Water-jetting (hydrodemolition)	High pressure water jet from a unit with a movable nozzle	Yes	Effective, selective, does not damage reinforcement or concrete, improved working environment	Water handling, removal in frost degrees, costs for establishment

METHODS OF SURFACE ROUGHNESS CHARACTERIZATION ANALYZED IN THE PROJECT


Development of Specifications and Performance Criteria for Surface Preparation Based on Issues Related to Bond Strength

Research and Development Office
Science and Technology Program

American Concrete Institute Foundation
Concrete Research Council,

Final Report ST-2017-2886-1

- *Concrete surface profile* (CSP), in accordance with ICRI Guideline No. 310.2R-2013.
- *Sand patch test*, in accordance with ASTM E965 (similar to EN 13036-1:2010) and EN 1766.
- *Mechanical profilometry*.
- *Laser technique*.
- *Interferometric profilometry*.

CONCRETE SLABS TESTED IN THE PROJECTS

Group A: Grinding (GR), sandblasting (SB), shotblasting (SHB20, SHB35 and SHB45, with treatment times of 20, 35, and 45 seconds, respectively), hand milling (HMIL) and mechanical milling (MMIL); untreated concrete samples (NT) were also tested as a control;

Group B: Polishing (PL), dry sandblasting (SB-D), jack hammering (JH) and water jetting at 250 MPa pressure (HD);

Group C: Gentle surface preparation methods were used to obtain profiles of similar amplitude and low-level microcracking: brushing (NT), wet sandblasting (SB-W), scarifying (SC) and water jetting at 12 MPa pressure (LC).

VISUAL OBSERVATION (1)

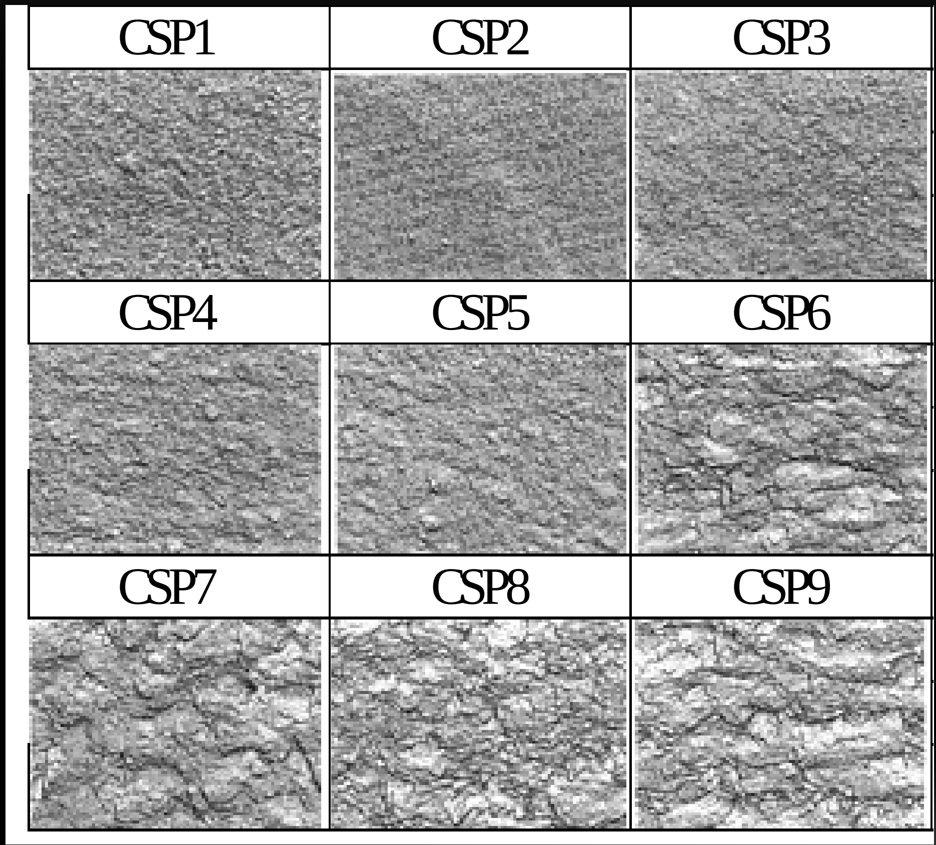
grinding

sandblasting

shotblasting

milling

VISUAL OBSERVATION (2)



Surface preparation methods	CSP
Detergent scrubbing	1
Low-pressure water cleaning	1
Acid etching	1–3
Grinding	1–3
Abrasive blasting (sand)	2–5
Steel shotblasting	3–8
Scarifying	4–9
Needle scaling	5–8
Water jetting	6–9
Scabbling	7–9
Flame blasting	8–9
Milling/rotomilling	9

SAND PATCH TEST

ASTM E965 (very similar to EN 13036-1). The surface roughness is characterized using glass or sand particles by the mean texture depth (MTD) :

$$MTD = \frac{4V}{\pi D^2}[mm]$$

EN 1766 The surface roughness is characterized using sand particles by the surface roughness index (SRI)

$$SRI = \frac{V}{D^2} \cdot 1272$$

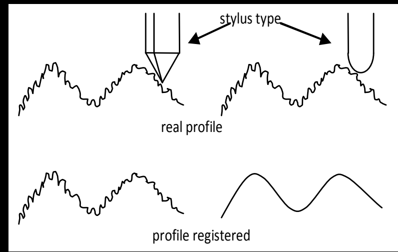
V = 25 mL

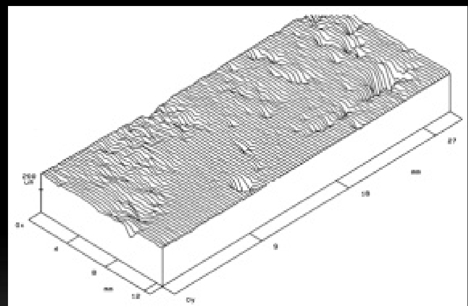
V = volume of granular material [mm^3]; D = diameter of circle covered by granular material [mm]

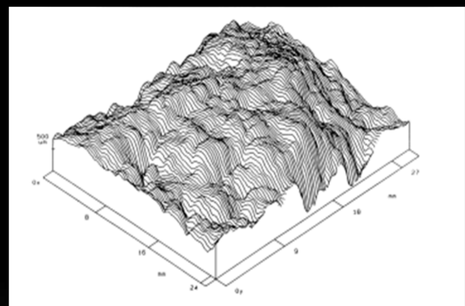
MECHANICAL PROFILOMETER

L.Courard, M. Nélis

a high-precision extensometer is moved over the entire. surface to obtain a 3D map (with x, y and z coordinates) from which morphological parameters are computed

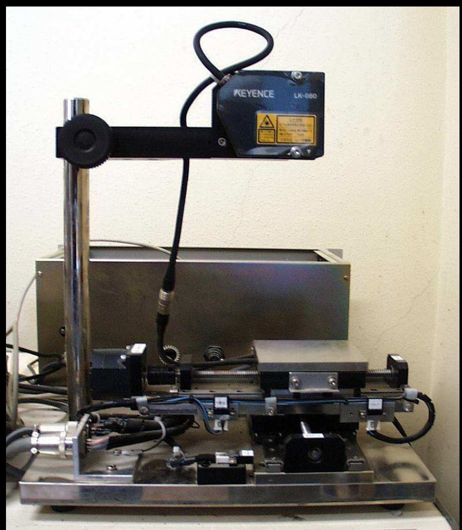


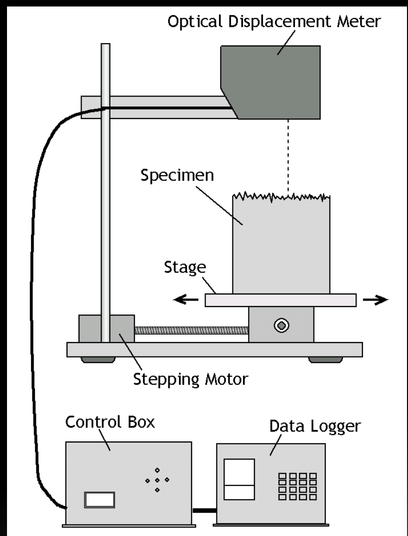


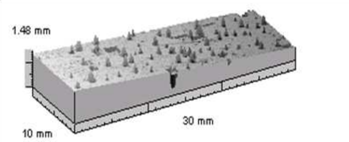
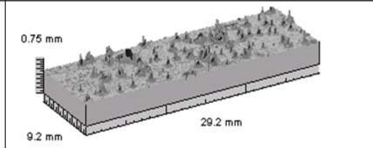
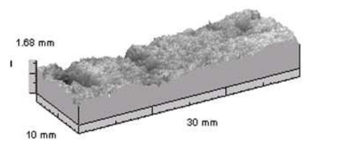
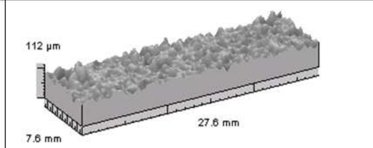
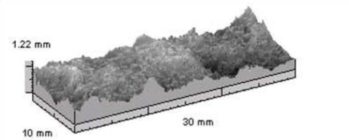
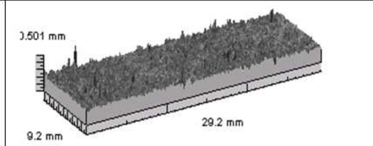
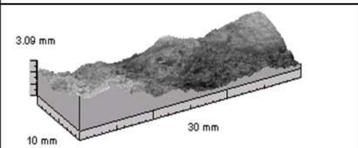
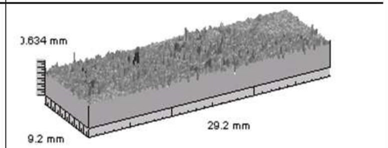
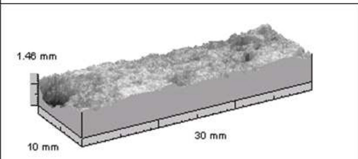
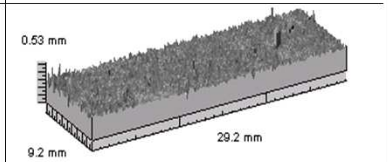
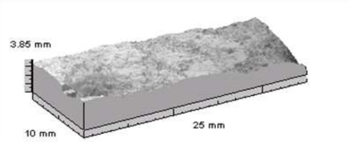
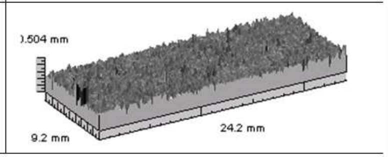


LASER PROFILOMETER

the superficial elevation (distance from the laser beam source to the object) of each point is calculated on the basis of the laser beam transit time.

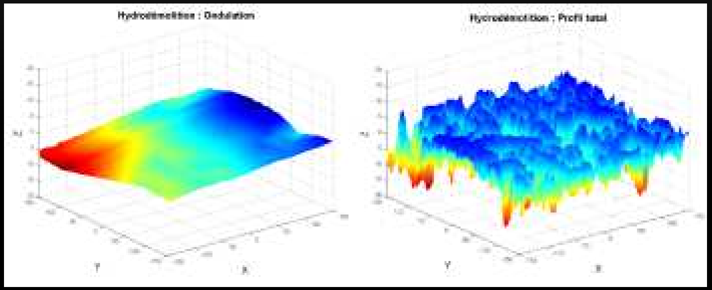


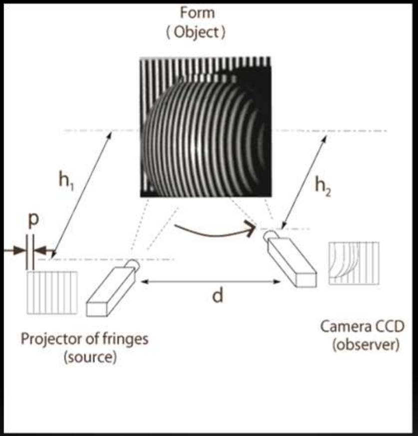


Treatment	Waviness	Roughness
As-received, no treatment NT		
Grinding GR		
Sandblasting SB		
Shotblasting 35s SHB35		
Hand Milling HMIL		
Mechanical Milling MMIL		

INTERFEROMETRIC PROFILOMETRY

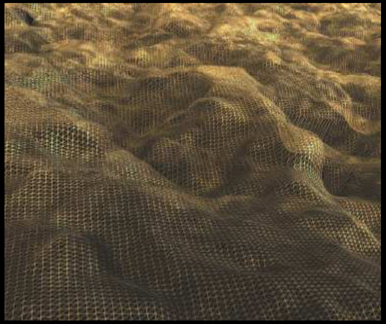
based on observation and analysis of the shadow produced by the superficial roughness of the surface (moiré fringe pattern principle)



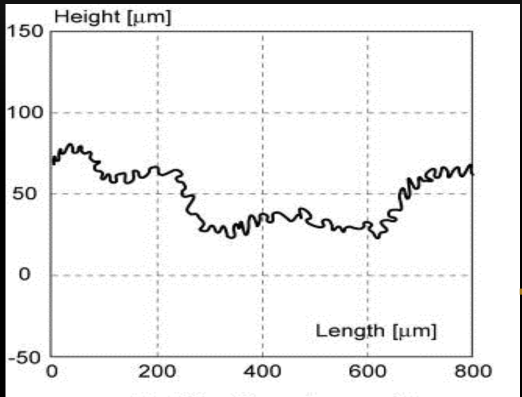


Matemathical

transformation

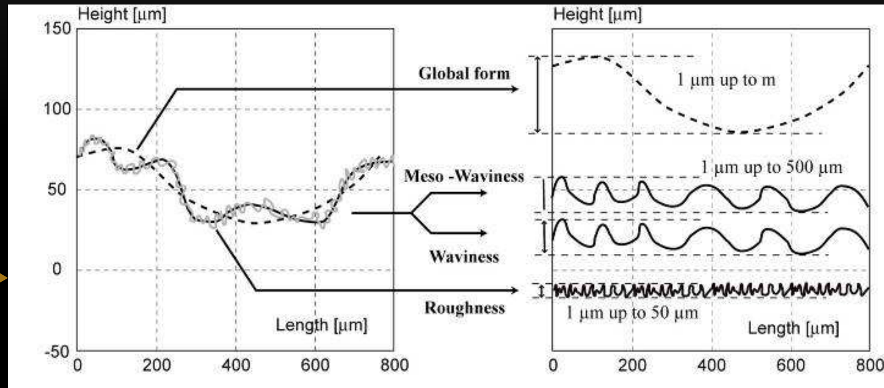


GEOMETRICAL PARAMETERS OF SURFACE STRUCTURE ACC. PN-EN ISO 4287 (1):



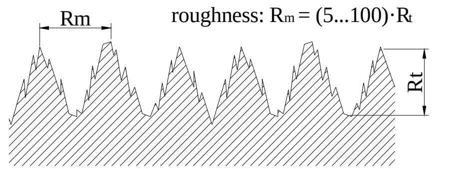
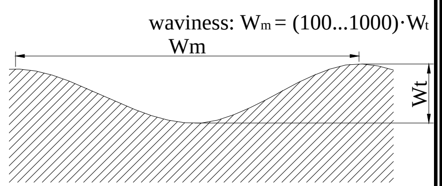
Profile of roughness of a surface of study

profile filtration



Decomposition of the profil roughness

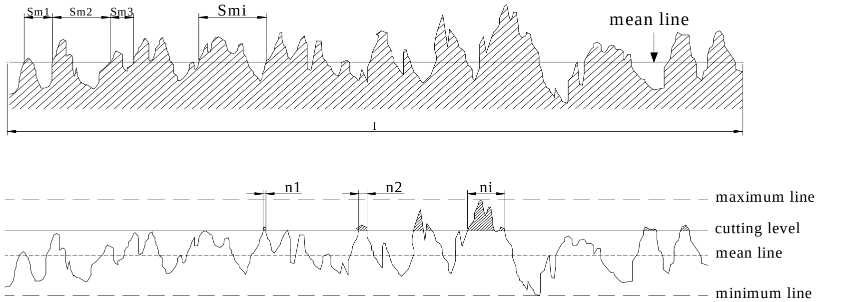
Result of this decompostion for 4 scales

Roughness	<u>high frequencies</u> gap between grooves (amplitude) R_m is 5-100 times the depth R_t	
Waviness	<u>mean frequencies</u> amplitude W_m is 100-1000 times the depth of holes W_t	

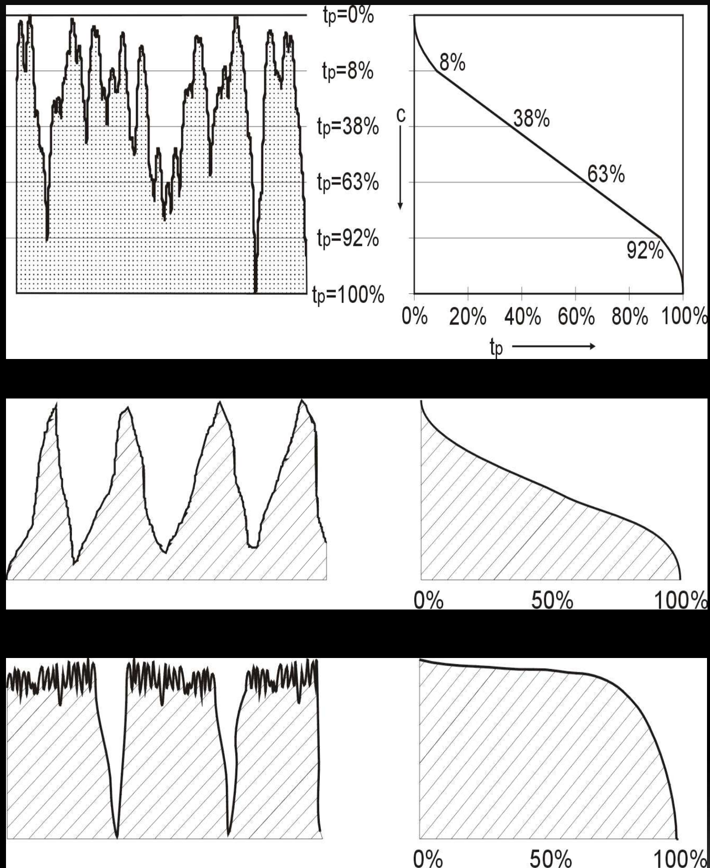
GEOMETRICAL PARAMETERS OF SURFACE STRUCTURE ACC. PN-EN ISO 4287 (2):

Sym-bol	Parameters	Definition
m_x	mean value and line	line whose height (mean value) is determined by minimal sum square deviation of the profile defined as follows: $X = \min \sum y^2(x)$
X_p	max peak height	distance between the highest point of the profile and the mean line
X_m	max valley depth	distance between the lowest point of the profile and the mean line
X_t	max height	maximum distance between the lowest and the highest point of the profile and it's equal X_t = max (X_p + X_m)
X_a X_a'	arithmetic mean deviation	mean departure of the profile from the reference mean line as follows: $X_a = \frac{1}{l}\int_0^l \lvert y(x) \rvert dx$, approximated by $X_a' \approx \frac{1}{n}\sum_{i=1}^{n} \lvert y_i \rvert$
X_q	Root mean square deviation	statistical nature parameter it is defined in the limits of the cut-off length $X_q = \frac{1}{l}\int_0^l y^2(x)dx$

Sy m-bol	Parameters	Definition
S_k	skewness of surface height distribution	a measure of asymmetry of profile deviations about the mean line, as follows: $S_k = \frac{1}{R_q^3}\frac{1}{n}\sum_{i=1}^{n} Y_i^3$
S_m	mean period of profile roughness	mean value of mean line including consecutively a peak and a valley S_{mi}, as follows: $S_m = \frac{1}{n}\sum_{i=1}^{n} S_{mi}$
n_p	bearing length	sum of partial lengths ni corresponding to the profile cut by a line parallel to the mean one for a given cutting level
t_p	bearing length ratio	ratio between bearing length and cut-off length, given as a percentage (%): tp = np/l.



GEOMETRICAL PARAMETERS OF SURFACE STRUCTURE ACC. PN-EN ISO 4287 (3):

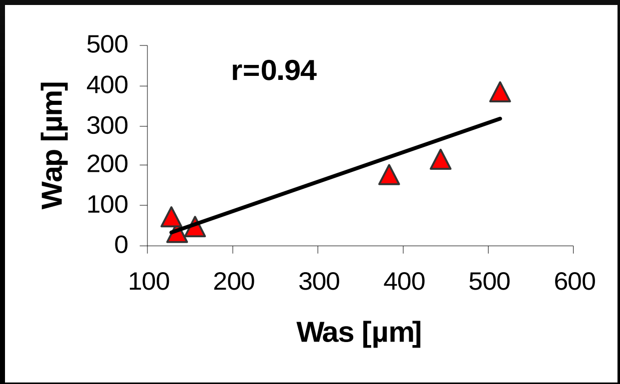


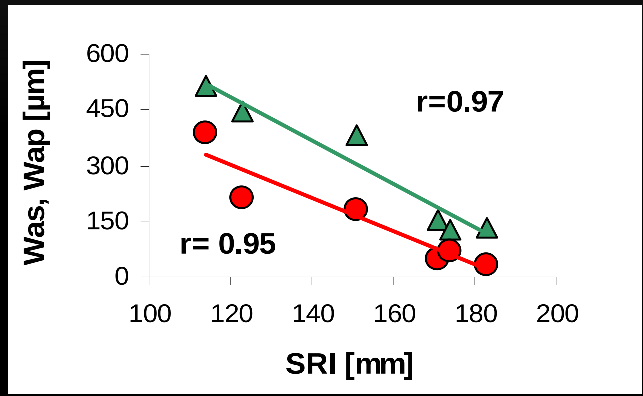
Bearing curve

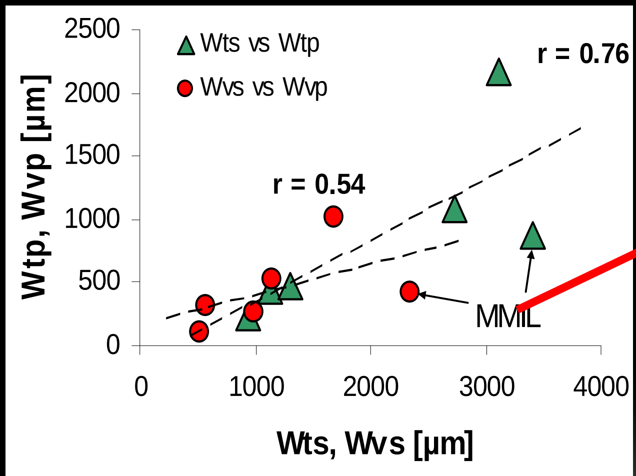
(Abbot's curve)

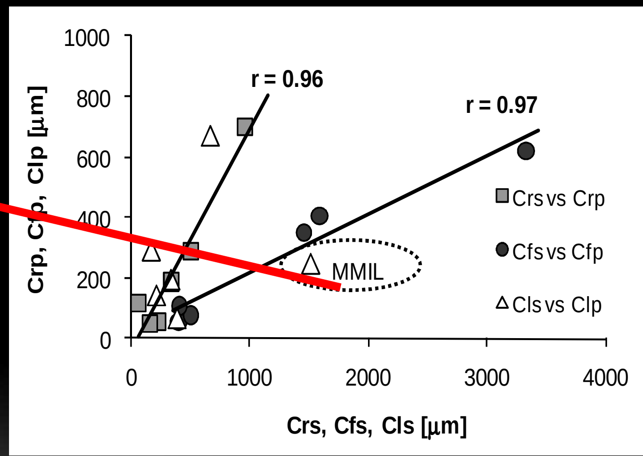
Sym -bol	Parameters	Definition
C_R	relative height of the peaks	gives an idea of significance of the volume of very high peaks above the reference line
C_F	depth of the profile	excluding high peaks and deep holes gives information on surface flatness; a lower value of C_F means an important surface flatness
C_L	relative depth of the holes	gives an idea of the significance of the volume of voids under the reference line

MECHANICAL (P) VS. LASER (S) PROFILOMETRY (1)

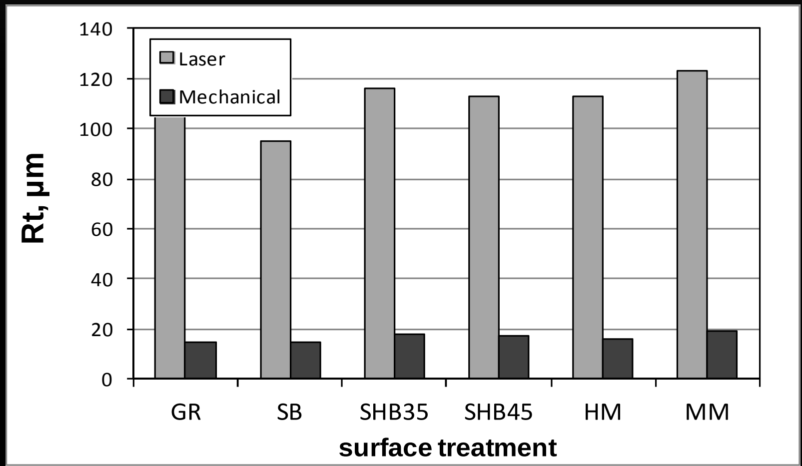


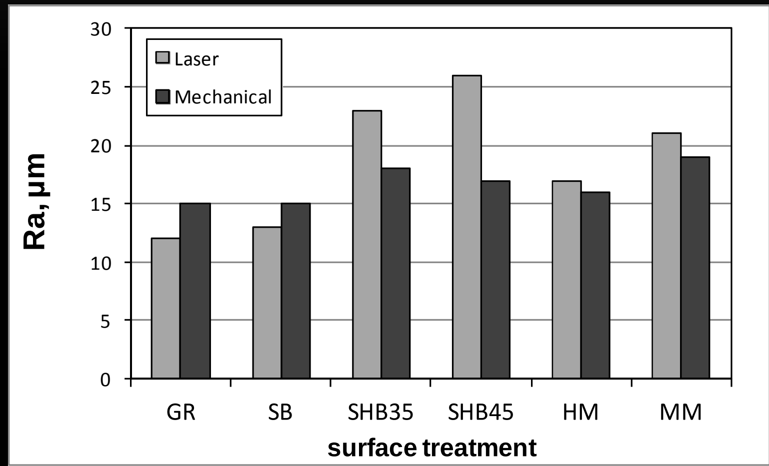






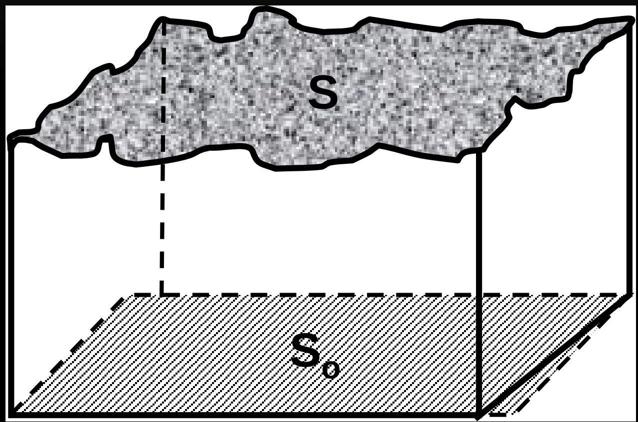
MECHANICAL (P) VS. LASER (S) PROFILOMETRY (2)





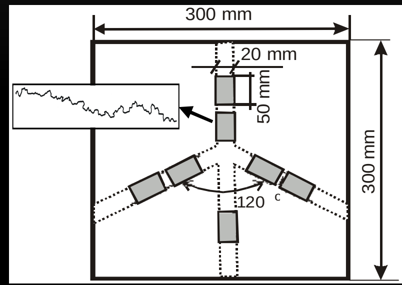
surface treatment technique does not have much influence on microroughness (high-frequency waves). The waviness parameters actually need to be determined in order to assess surface roughness prior to repair

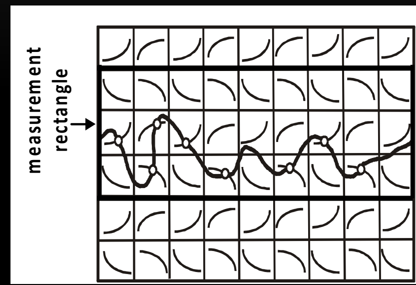
SURFACE ROUGHNESS CHARACTERIZATION WITH THE MICROSCOPIC OBSERVATION METHOD

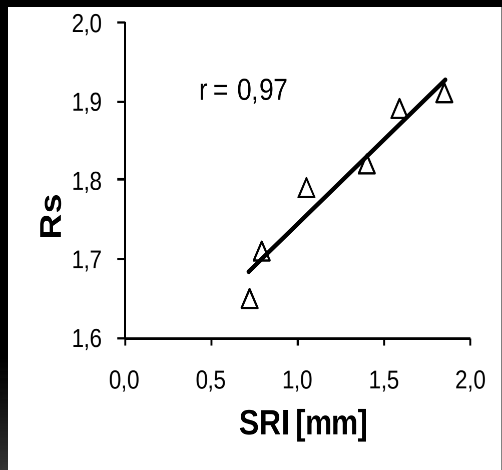


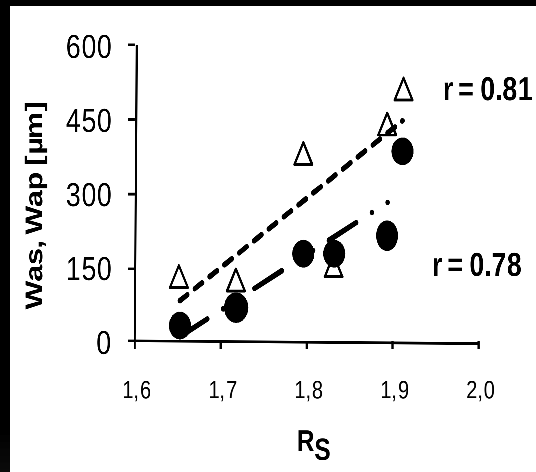
$$R_S = S/S_O$$

surface roughness is related to the energy being dissipated during material decohesion

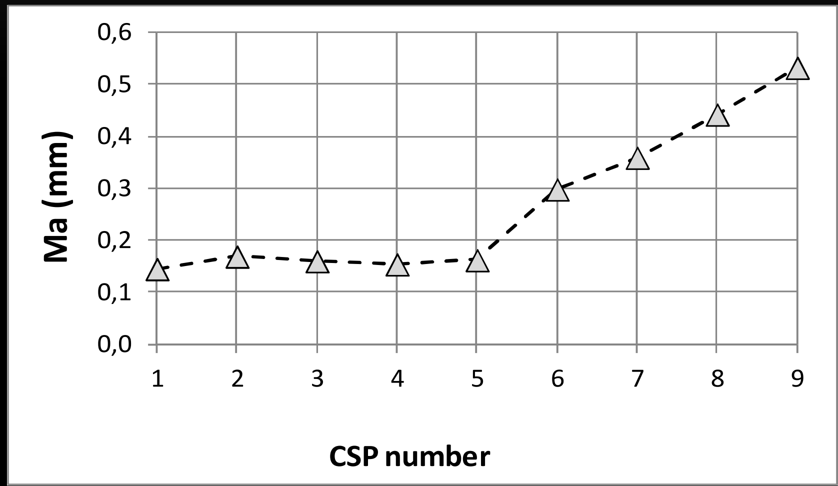








INTERFEROMETRY VS CSP

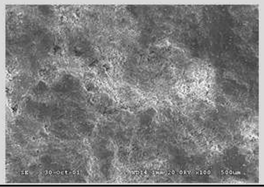
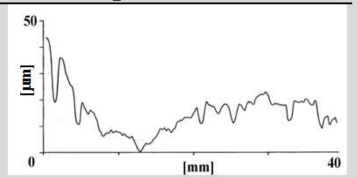
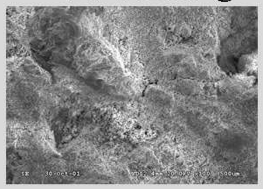
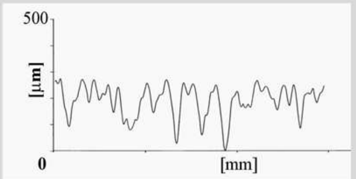
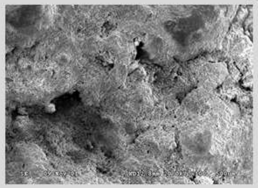
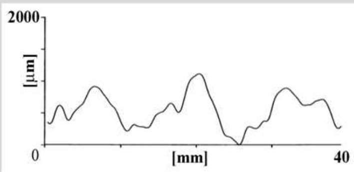
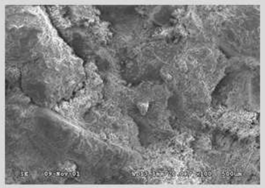
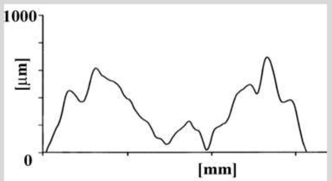


The actual CSP plates are rather narrow with respect to the spectrum of CSPs obtained with actual surface preparation techniques.

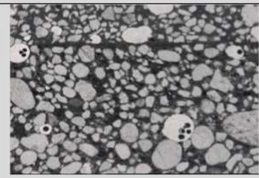
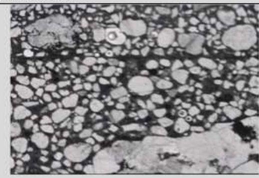
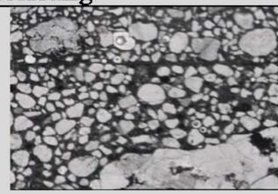
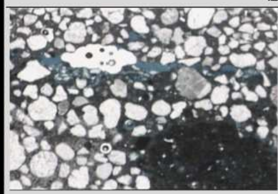
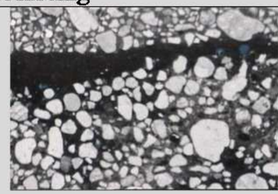
SUMMARY

- Characterization of surface roughness is an important aspect in assessing a concrete substrate prior to repair. Various techniques have recently been available for CSP characterization.
- The waviness parameters actually need to be determined in order to assess surface roughness prior to repair.
- Among the techniques available today, the best suited method for field assessment appears to be the CSP developed by ICRI.

ADHESION VS. SUBSTRATE QUALITY (2)

Example of surface view SEM - magnification 100x	Waviness profiles obtained with profilometer and selected parameters
No treatment 	 W_a = 5 µm; W_t = 39 µm
Sandblasting 	 W_a = 49 µm; W_t = 434 µm
Shotblasting 	 W_a = 215 µm; W_t = 1086 µm
Milling 	 W_a = 179 µm; W_t = 867 µm

C20/25

No treatment	
	
Sandblasting	
	
Shotblasting	
	
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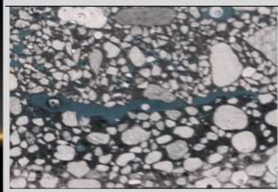
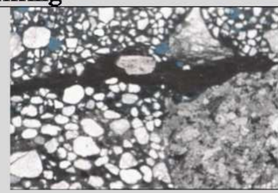
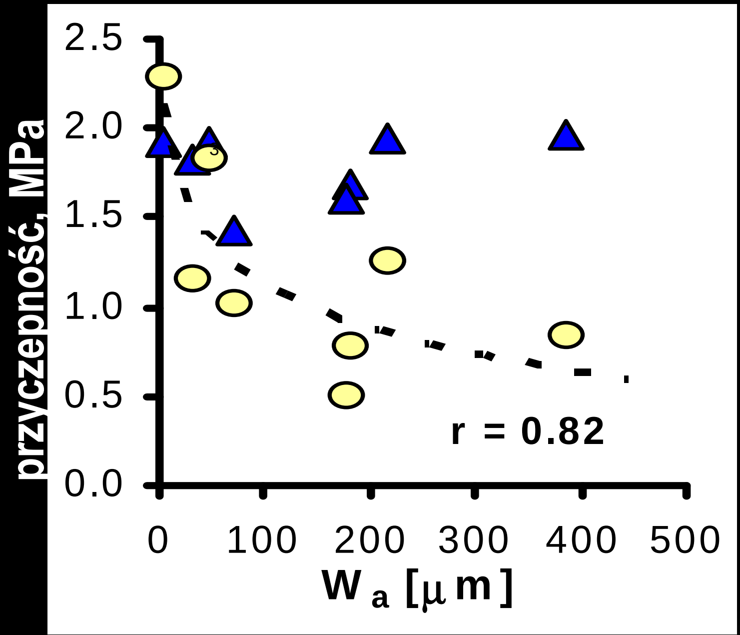
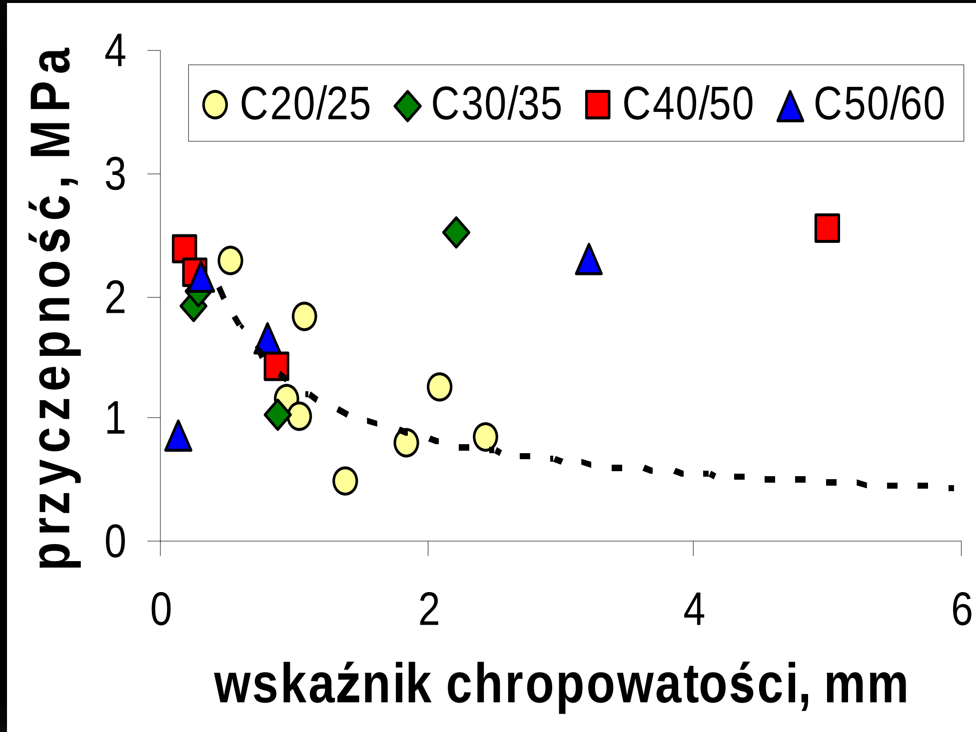
	

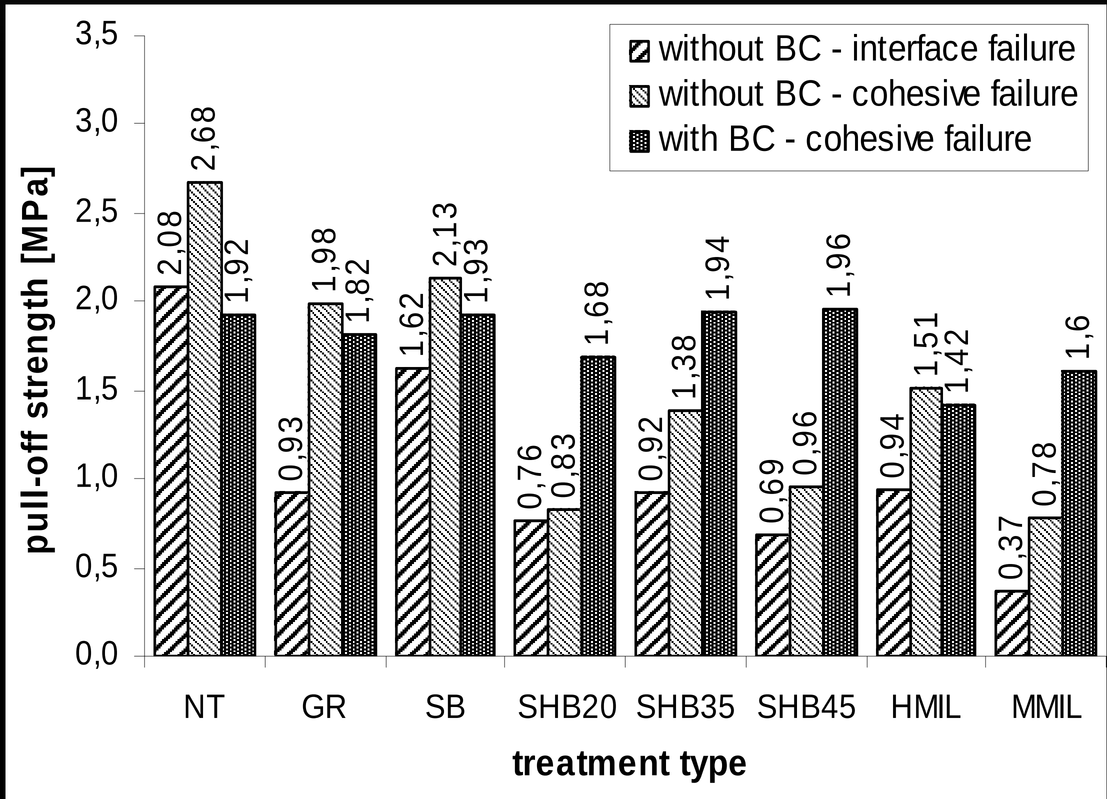
ADHESION VS. SUBSTRATE QUALITY (2)

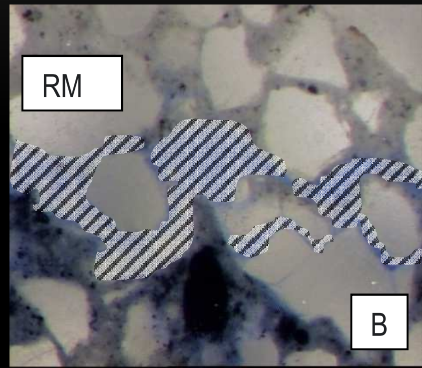
C20/25

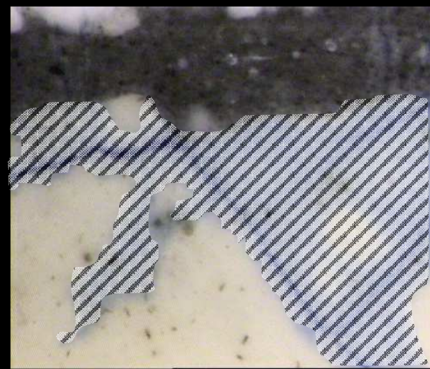




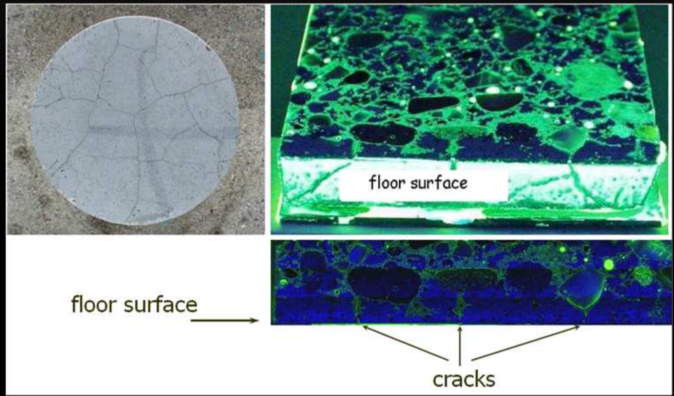
ADHESION VS. SUBSTRATE QUALITY (3)

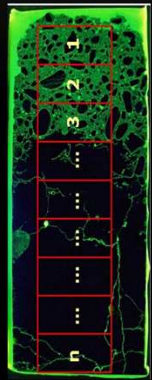


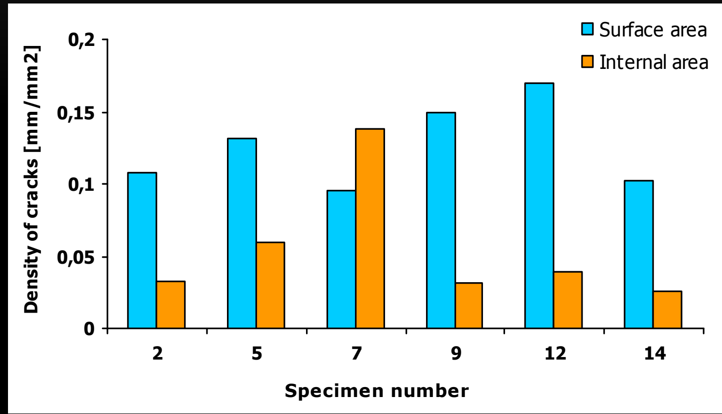


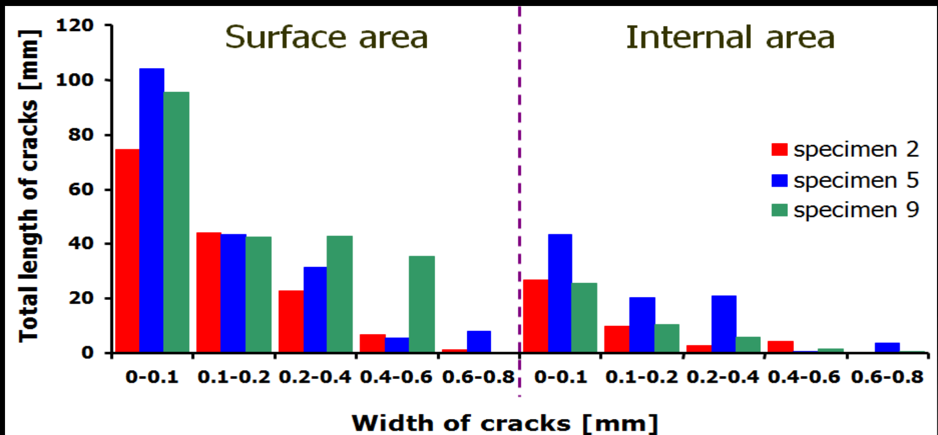


MICROCRACKING EVALUATION (1)





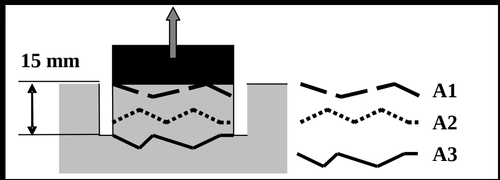


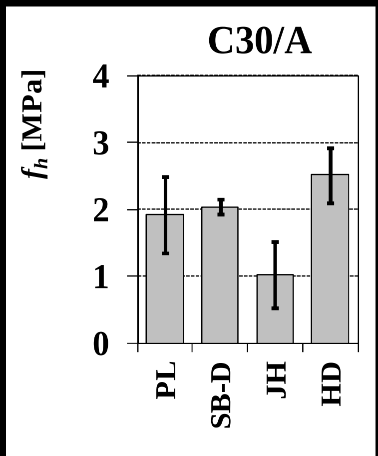


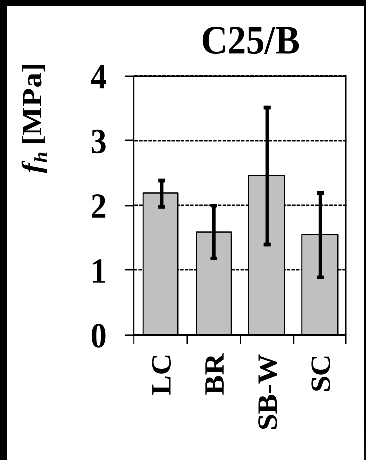
M.Glinicki, A.Litorowicz, 2005

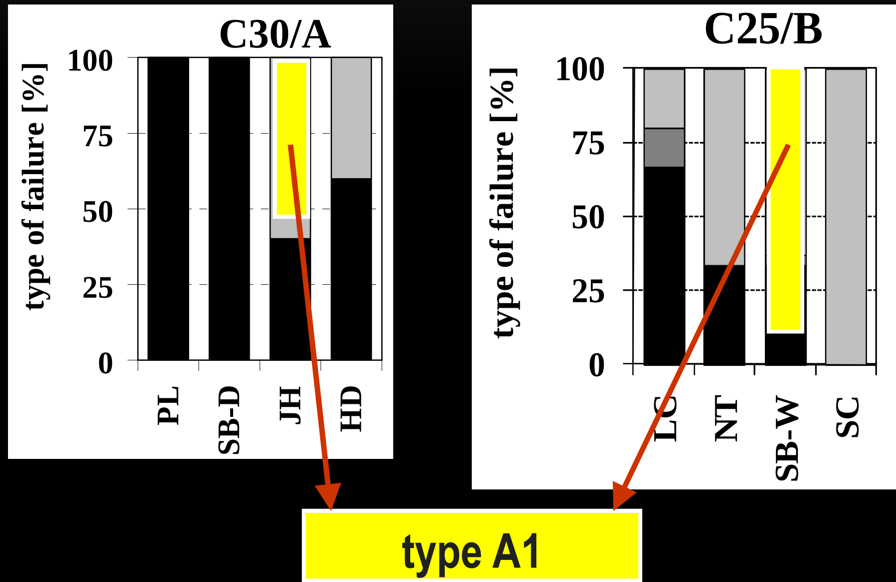
MICROCRACKING EVALUATION (1)

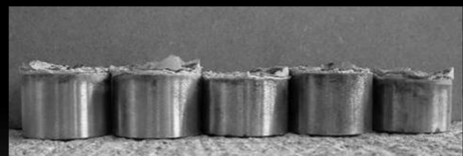
f_{hs}



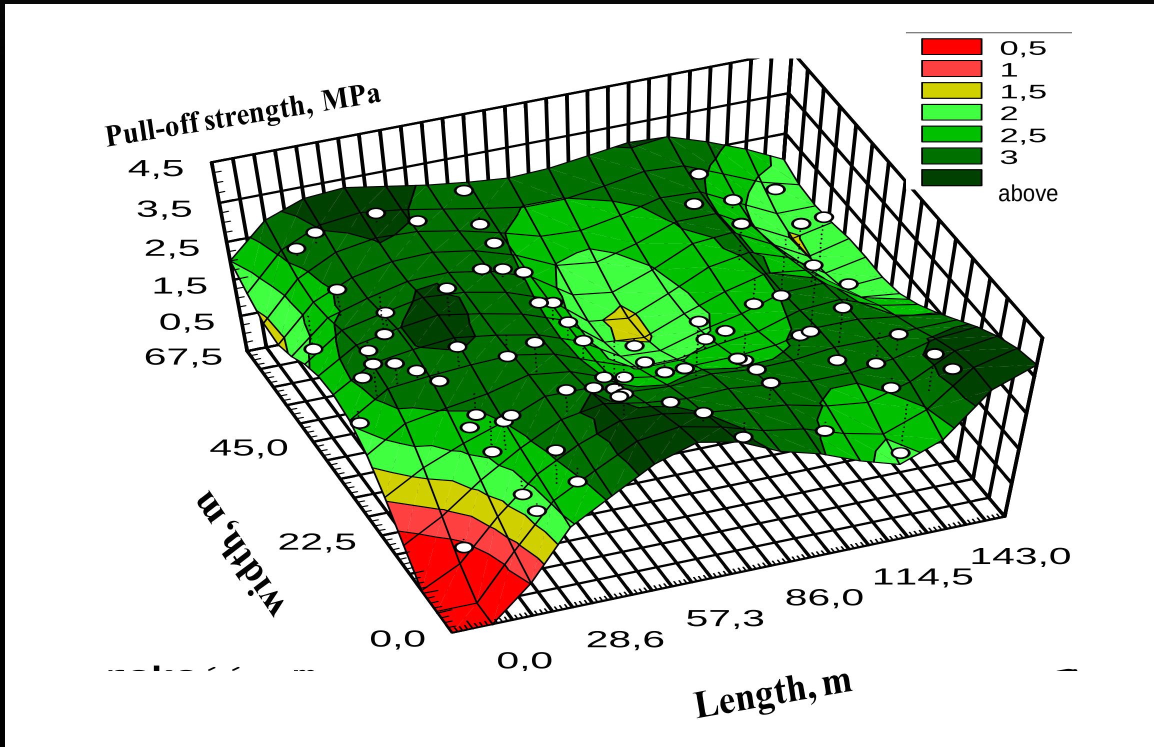








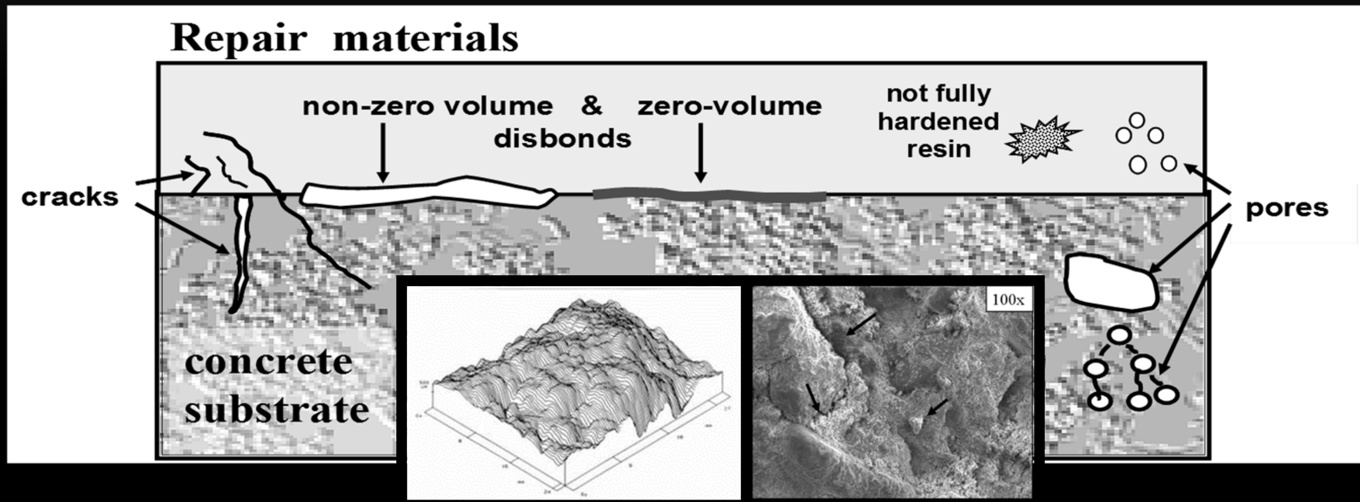
PULL OFF IS THE MOST COMMON TEST



→ NDT!

Impact-echo
Ultrasonic
GPR

REPAIR SYSTEM AS AN OBJECT OF NDT TESTING



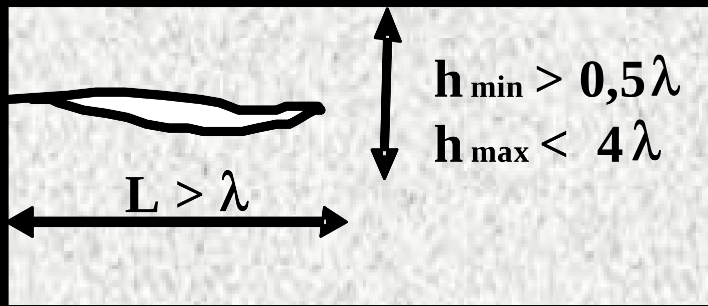
<u>DEFECT TYPES</u>

- *Adhesion* type (at the interface zone of RM-CS system): *non-zero volume debonding (delamination), zero-volume debonding, weak adhesion areas*

- *Cohesion* type (in repair material or/and concrete substrate): *porosity, cracks, honeycombing, unhardened resin (PC)*

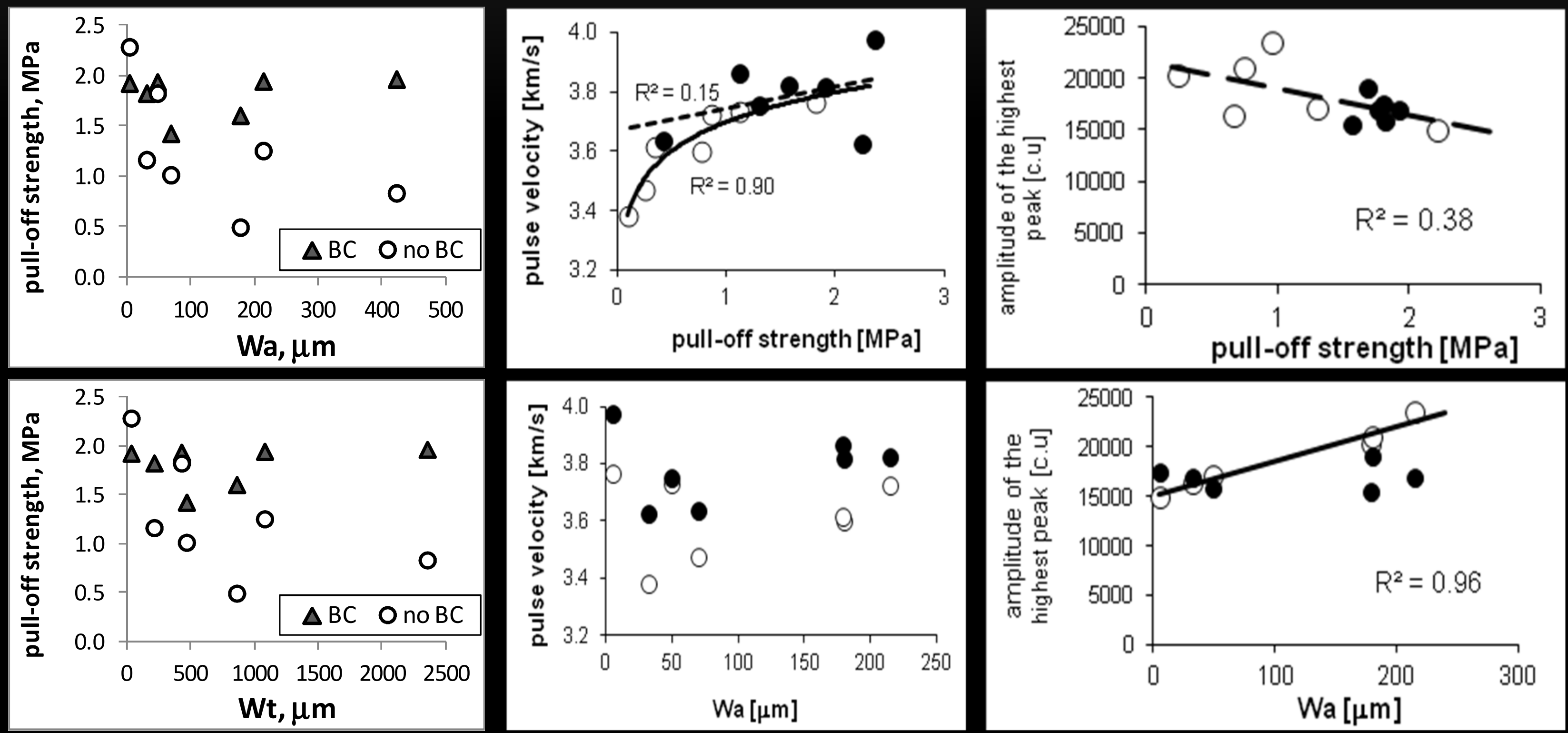
SELECTION OF NDT METHOD

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



$$R = \frac{A_r}{A_i} = \frac{Z_2 - Z_1}{Z_2 + Z_1}$$

RESULTS


pull-off strength, MPa
Wa, µm
▲ BC ○ no BC
pulse velocity [km/s]
pull-off strength [MPa]
R² = 0.15
R² = 0.90
amplitude of the highest peak [c.u]
pull-off strength [MPa]
R² = 0.38
pull-off strength, MPa
Wt, µm
▲ BC ○ no BC
pulse velocity [km/s]
Wa [µm]
amplitude of the highest peak [c.u]
Wa [µm]
R² = 0.96

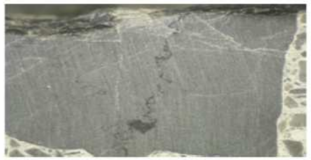
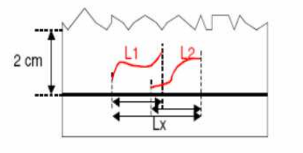
CONCRETE SUBSTRATE QUALITY (2)

	Group A	Group B
Concrete	C30/37, C40/50, C50/60	
Surface preparation	no treatment **NT** wet sandblasing **SB-W** scaryfication **SC** water jetting **LC**	polishing **PL** dry sandblasting **SB-D** jack hammering **JH** hydrodemolition **HD**

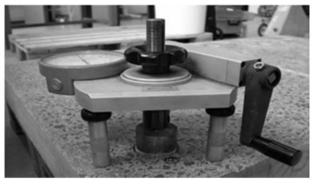
SRI [mm]



Total length of microcracks [mm]

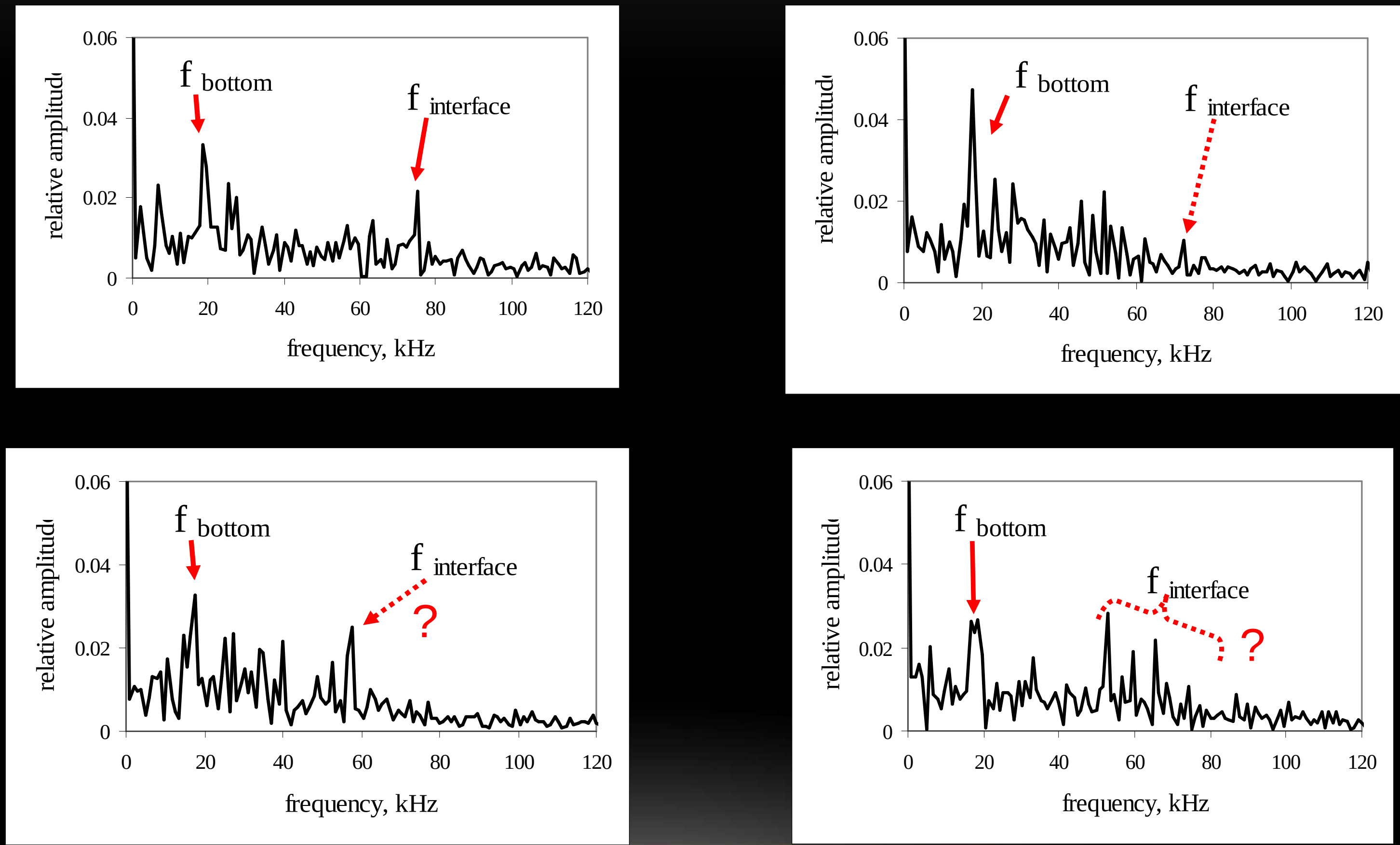
Bond strength (pull-off) [MPa]



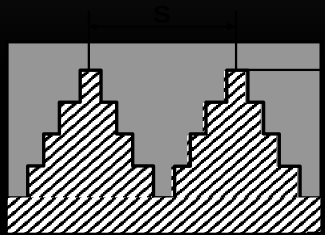
acc. EN 1542

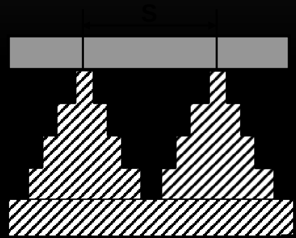
EFFECT OF CONCRETE SUBSTRATE PREPARATION (LAB)

a) polishing b) sandblasting

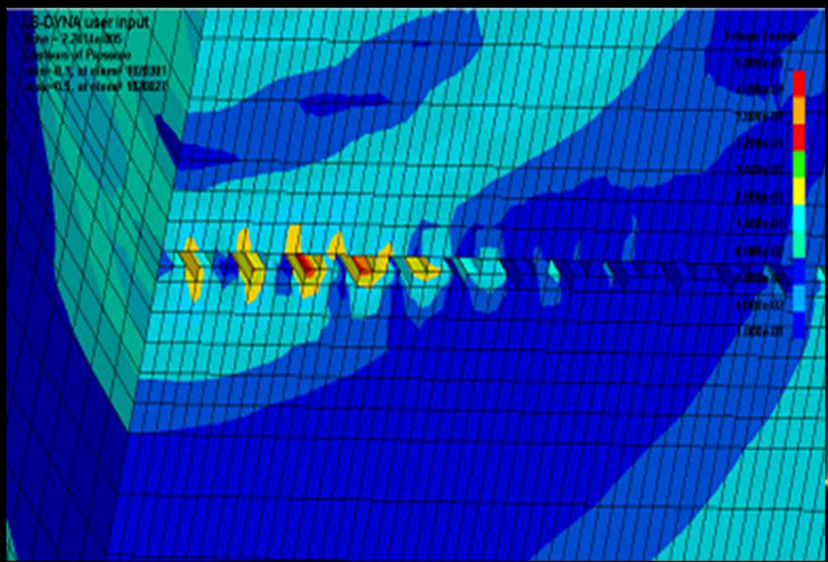


EFFECT OF CONCRETE SUBSTRATE PREPARATION (FEM)

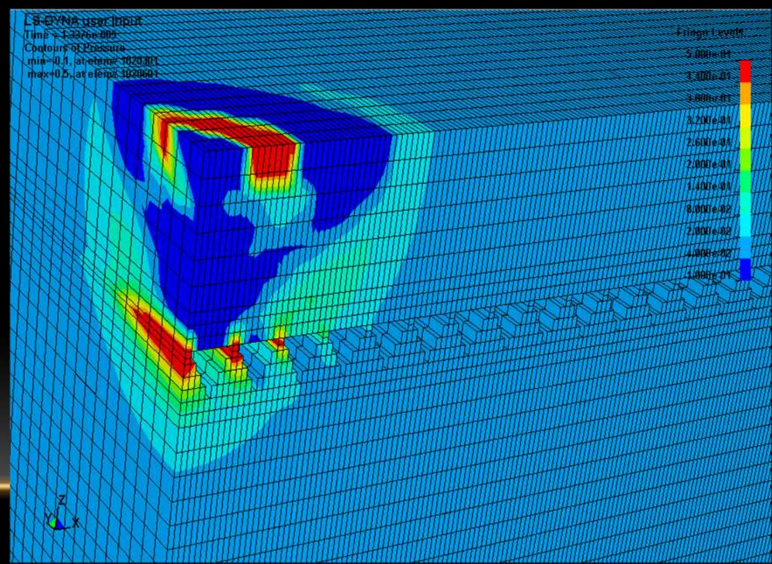




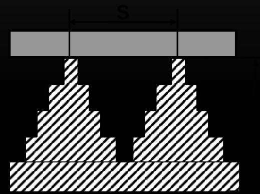
Sandblasting

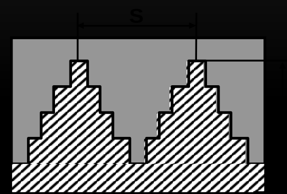


Hydrodemolition

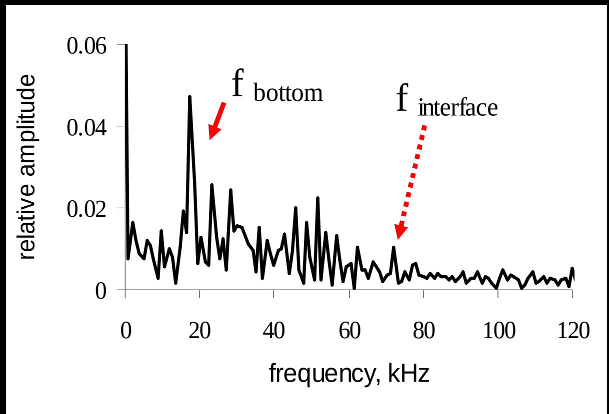


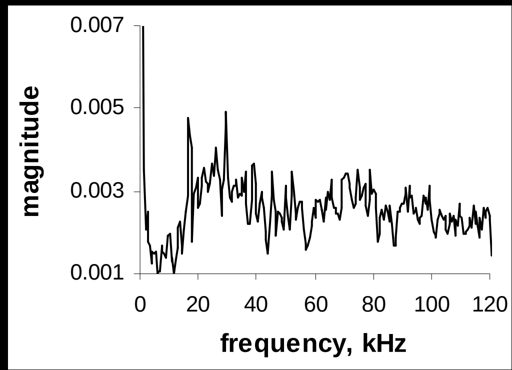
LAB *vs.* FEM

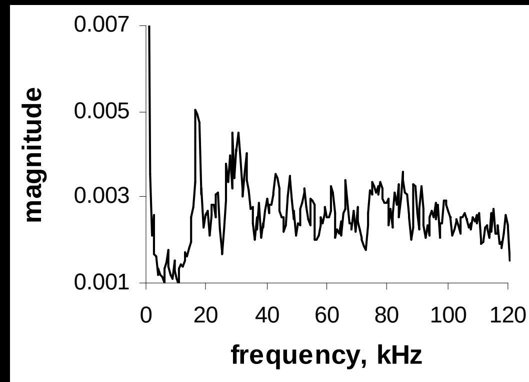




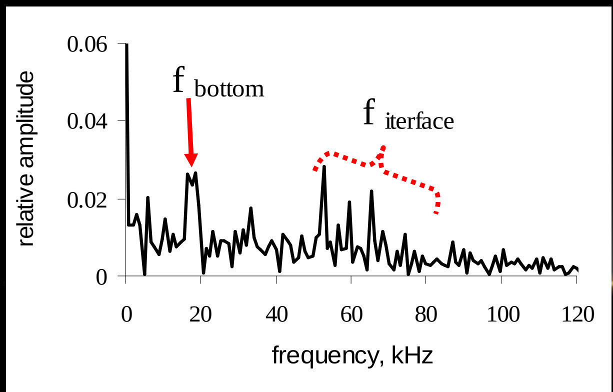
SB:

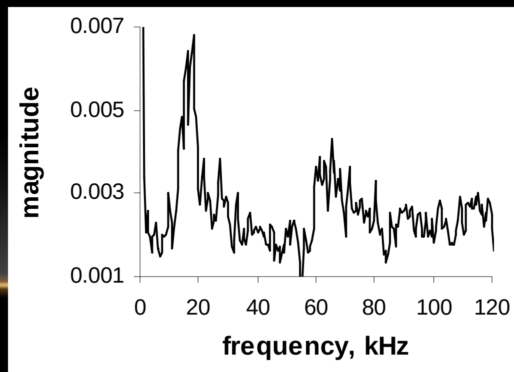


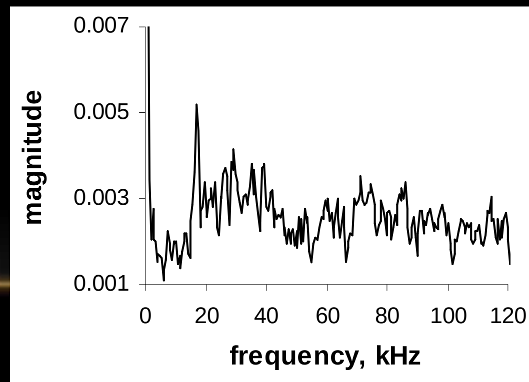




HD:







SUMMARY

- For the both IE and ultrasonic methods, the roughness and microcracking of the concrete substrate do not affect significantly the P-wave propagation through the repair system if the bond quality is sufficient
  - absence of large voids at the interface

SUMMARY

- Parameters describing roughness and microcracking of concrete substrate can be considered as important variables for improvement of reliability of the bond strength evaluation, using more advanced signal analysis of stress waves (e.g. wavelet approach)

CONCRETE

very good construction material

4^{th} successful

ICCRRR 2015

↓

Repair of concrete
Never ending story

ACKOWLEDGMENTS

- Concrete Research Council de l'American Concrete Institute (ACI)
- Conseil de Recherche en Sciences Naturelles et en Génie du Canada (CRSNG)
- Fonds de Recherche Québécois sur la Nature et les Technologies (FRQNT)
- U.S. Bureau of Reclamation (USBR)
- *Chaire CRSNG sur la Réparation durable et l'entretien optimisé des infrastructures en béton* à l'Université Laval
  (BASF, Euclid, Holcim, Hydro-Québec, Kerneos, King Packaged Materials, Lafarge, Ministère des Transports de Québec, Ville de Montréal, Ville de Québec, W.R. Grace & Co.)
- Programmes de coopération scientifiques des gouvernements polonais, québécois et de Wallonie-Bruxelles

DZIĘKUJĘ ! MERCI !

z Bożej Łaski
MY MIKOŁAJ I
Cesarz Wszech Rossyi, Król Polski,
etc. etc. etc.

•January 4, 1826 - the Preparatory School for the Institute of Technology,

•June 8, 1898 - Tsar Nikolaus II Institute of Technology,

•November 15, 1915 - Warsaw University of Technology (with Polish as the language of instruction).