Role of hydrogen in service degradation of the physical and mechanical properties of structural steels

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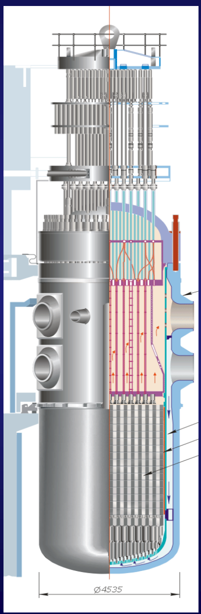
Scope of Lecture

1. Introduction
2. The regularities and effect of hydrogen on degradation of properties
3. Dissipated damaging as the peculiarity of in-service degradation
4. In-laboratory modeling of in-service degradation
5. Evaluation of in-service degradation by monitoring of electrochemical properties
6. New challenges in material degradation
7 . Conclusion

1. Introduction

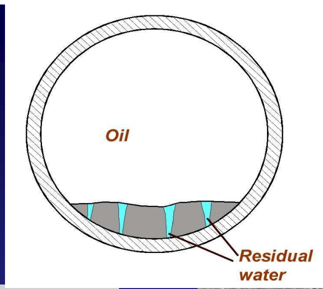
Degradation of nuclear and heat power station, oil refinary steels

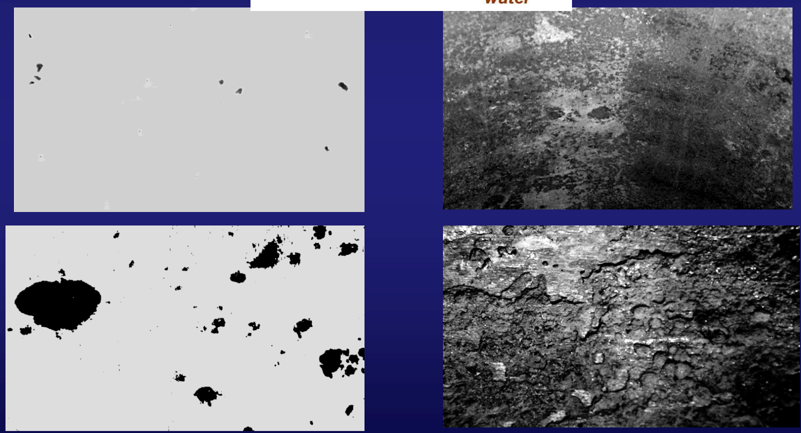


Degradation of portal cranes

Failure of transit gas pipeline

2. The regularities and effect of hydrogen on degradation of properties





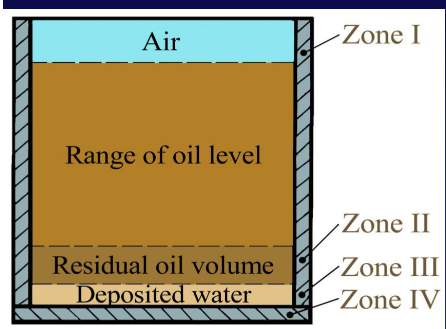
top

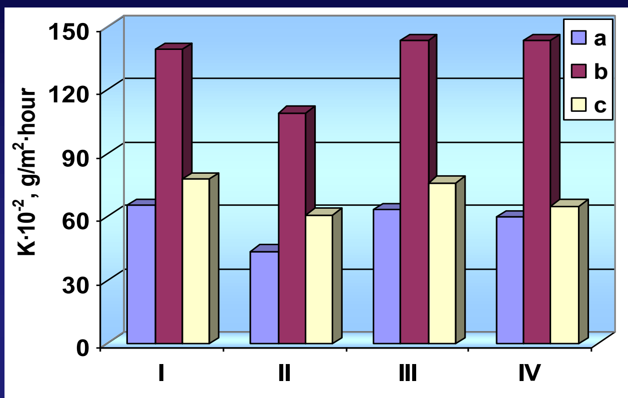
bottom

Oil pipeline

Gas pipeline

Oil storage tank steel

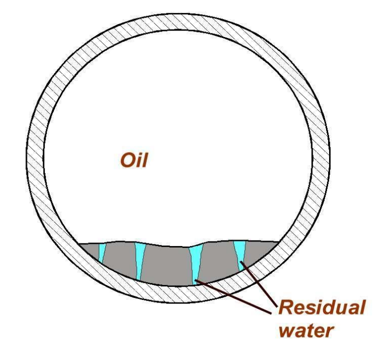


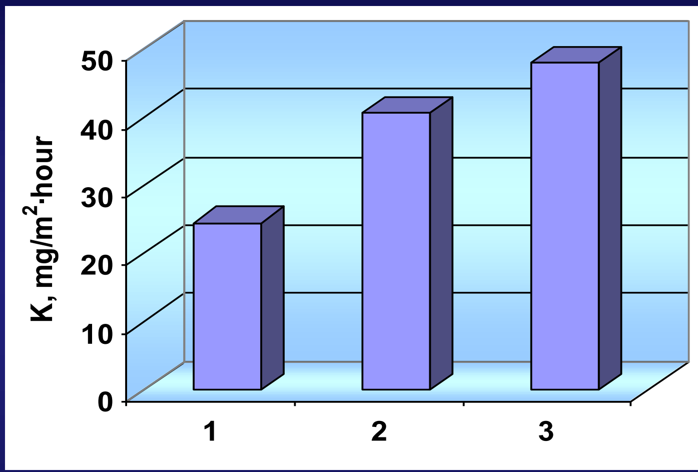


The low carbon (0.2 C) steel, 30 years of service

Indicator	Zone			
	I	II	III	IV
Impact strength, [J/cm^2]	72	153	62	84

Transit oil pipeline

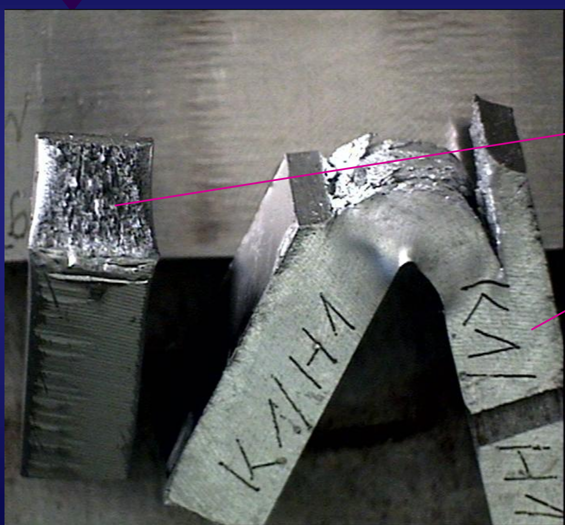


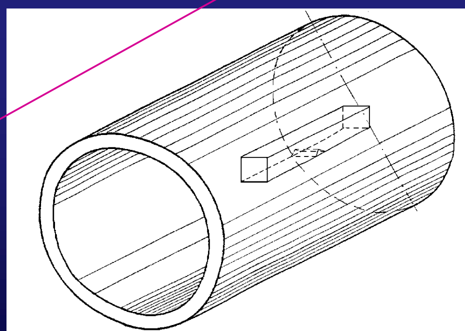


0.10C-1.6Mn-0.30Si steel, 28 years of service

KCV tests of transit oil pipeline steel

State	KCV, J/cm^2
virgin	180
“top”	95
“bottom”	??

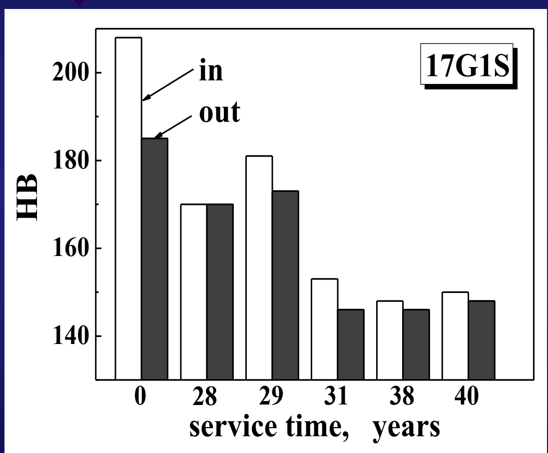


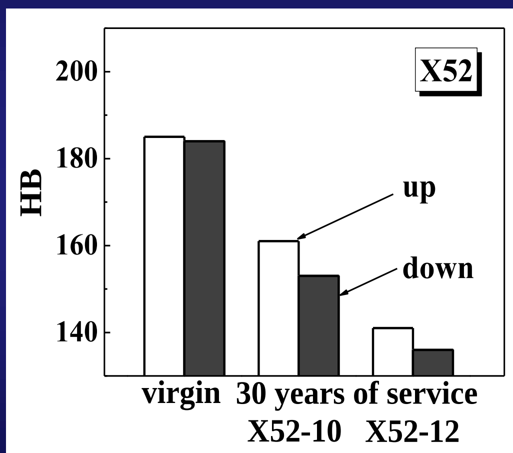


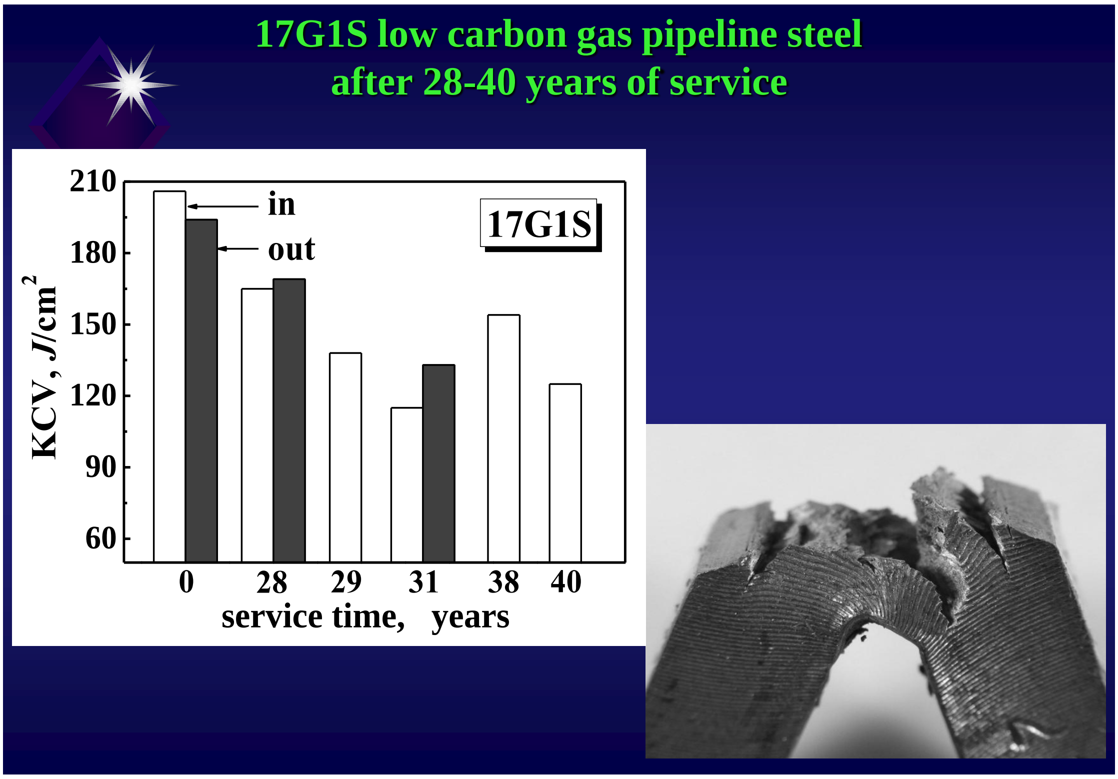
The peculiarities of in-service degradation of trunk gas pipeline steels

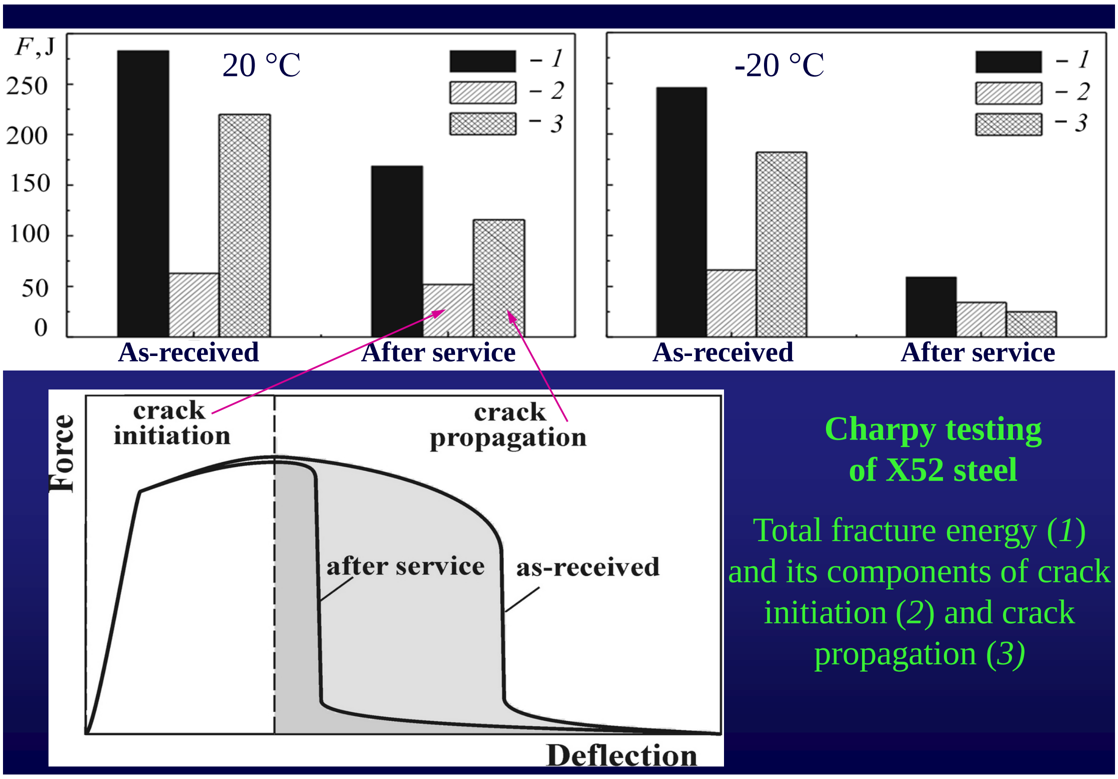
Steel	Service, years	Part of pipe	σ_{ys}, MPa	σ_{UTS}, MПa	RA, %	Elong, %	Hardening,	$J_i/J_{0.2}$, kN/m
X52	–		355	475	72,9	22.7	0.59	86/412
X52-12	30	Down	268	451	64.4	20.8	0.74	50/127
		Top	255	460	62.5	22.9		
X52-10		Down	362	536	54.6	29.7	0.82	37/79
		Top	335	538	55.0	28.8		
17G1S	–		378	595	79.0	20.2	0.58	203/315
	28		403	590	68.2	20.5		
	29		345	547	71.1	19.6	0.76	
	31		419	574	73.8	21.8		87/201
	38		357	520	73.1	25.4	0.97	
	40		302	515	69.2	26.3	0.75	

Low carbon gas pipeline steels after 28-40 years of service

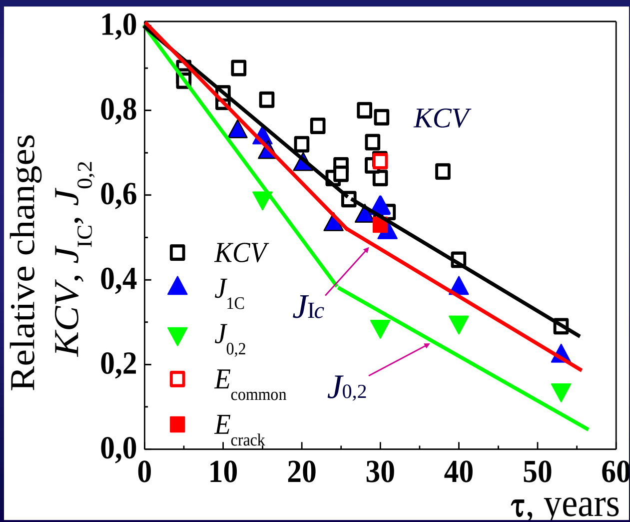


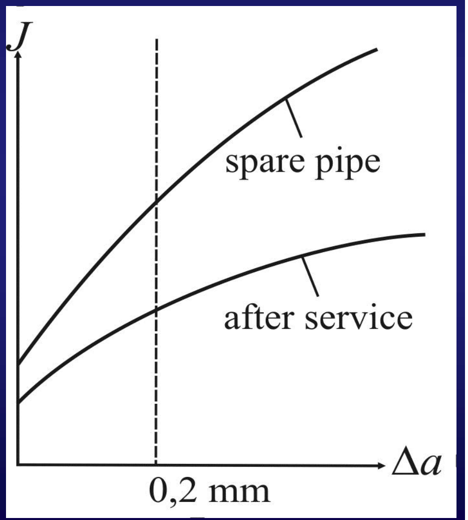



17G1S low carbon gas pipeline steel
after 28-40 years of service
KCV, J/cm²
210
180
150
120
90
60
in
out
17G1S
0
28
29
31
38
40
service time, years


F, J
250
200
150
100
50
0
20 °C
-20 °C
– 1
– 2
– 3
As-received
After service
As-received
After service
Force
crack initiation
crack propagation
after service
as-received
Deflection
Charpy testing of X52 steel
Total fracture energy (1) and its components of crack initiation (2) and crack propagation (3)

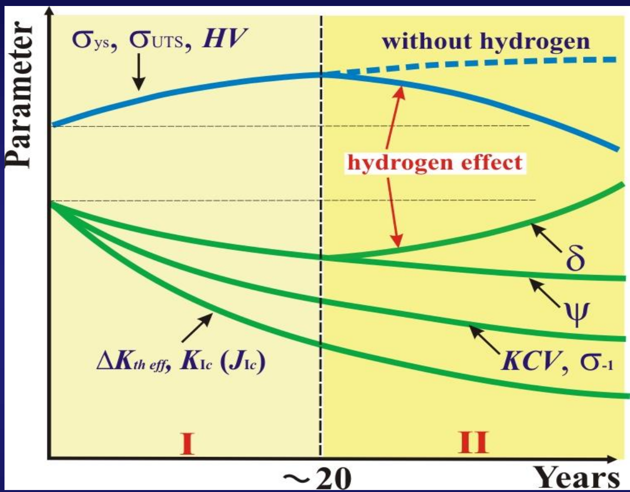
Comparison of sensitivity to degradation the characteristics of brittle fracture resistance for some pipeline steels 14KhGS, 17GS, 17G1S, X52, X60

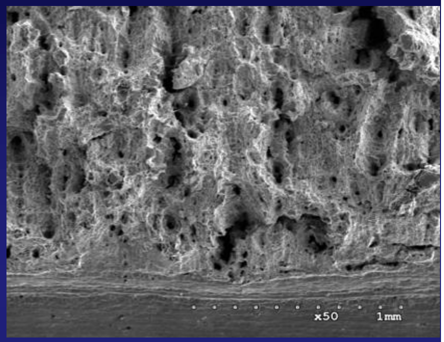


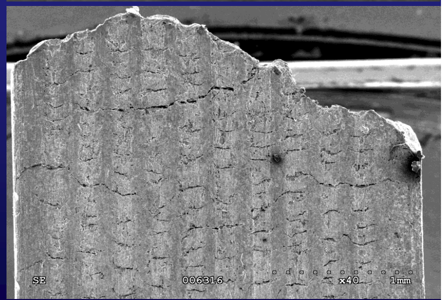


3. Dissipated damaging as the peculiarity of in-service degradation

Two principal stages of in-bulk material degradation







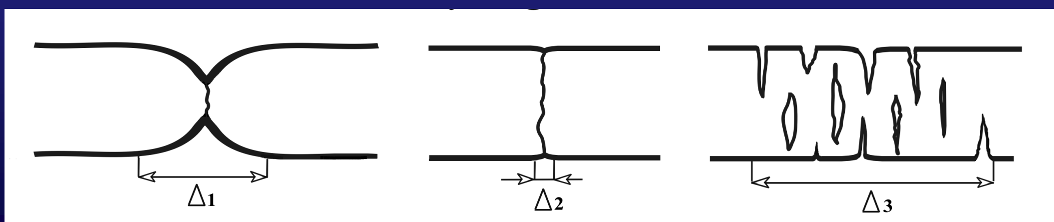
Deformation aging Damaging

30 years of service – critical age from the point of considering in-bulk material damages !

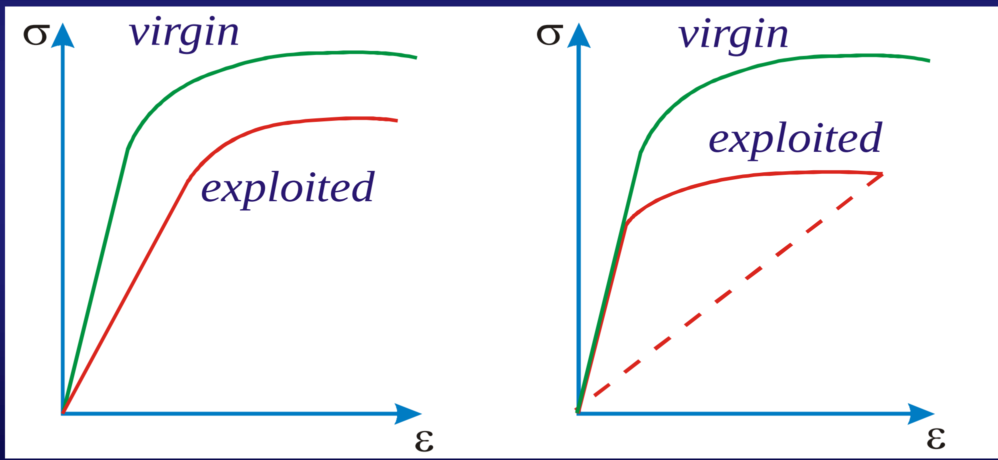
The phenomena of degradation caused by dissipated damaging

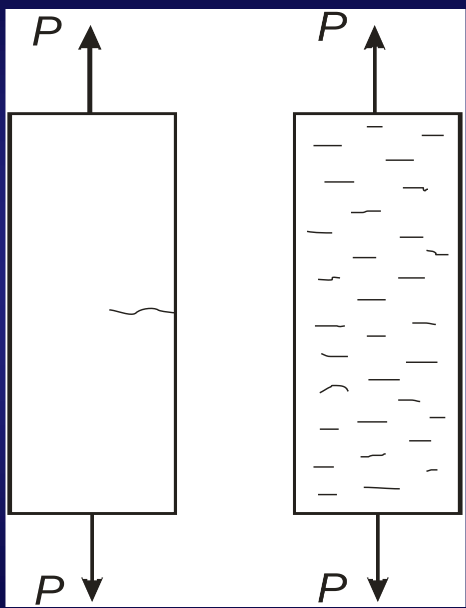
3.1. Reduction of strength and brittle fracture resistance is a special phenomenon of in-service degradation, caused by accumulation of defects.

3.2 This phenomenon is accompanied by an elongation increase and reduction of area with metal service.



3.3. Damaging become apparent in a decrease of (pseudo ?) elastic module (preliminary damaging) and a decrease of (pseudo ?) yield strength (creation of defects during loading in elastic region)





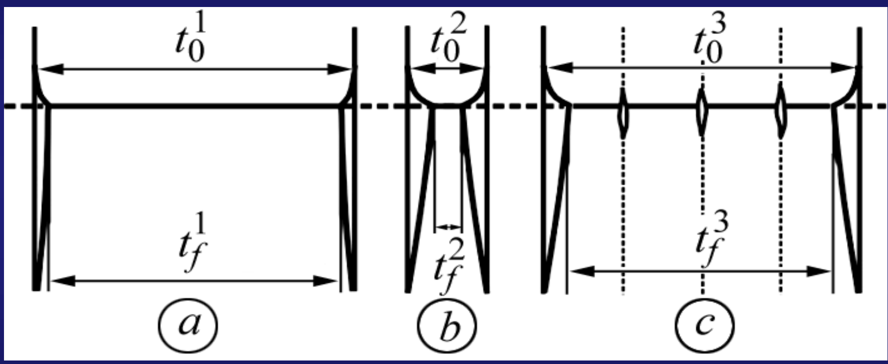
Compliance is higher

Elastic modulus is constant

Compliance is higher

Is elastic modulus constant ?

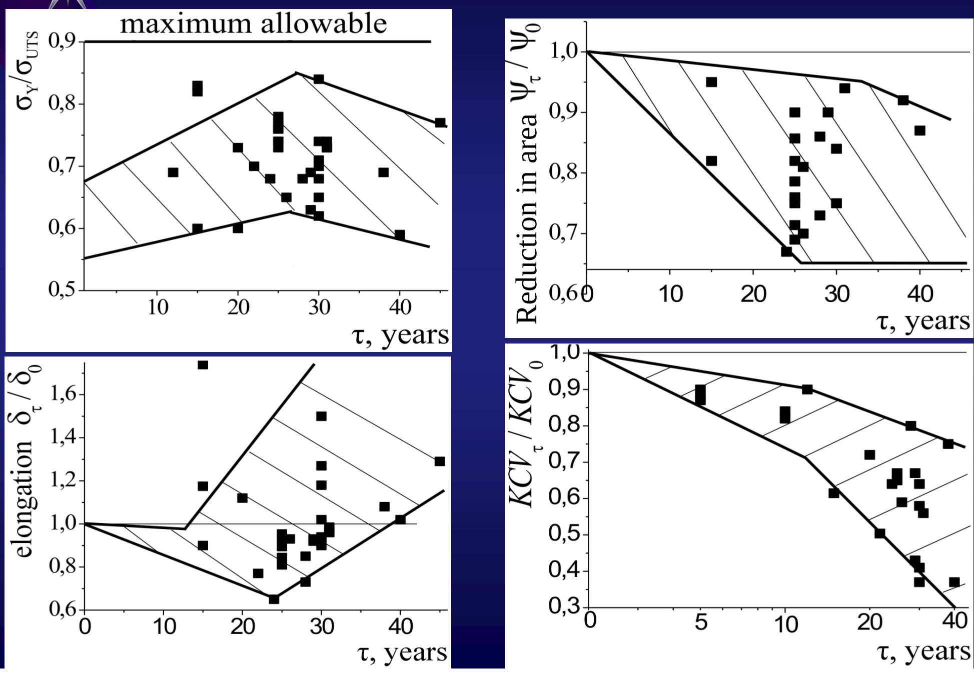
3.4. Thicker “lips of stretching” on fracture surface after fracture toughness tests are expected for virgin material



Deformation at the crack tip (dotted line) of specimens of different thickness in as-received state (*a*, *b*) and after service (*c*)

4. In-laboratory modeling of in-service degradation

Generelized data about in-service degradation of some mechanical properties



Usually artificial (in-laboratory) degradation consists in
a preliminary plastic deformation (10 %) with the following heating to 250 °C and holding 1 hour (Soviet standard GOST 7268-82).

It models a deformation aging, when strength, hardness are increased and brittle fracture resistance is decreased.

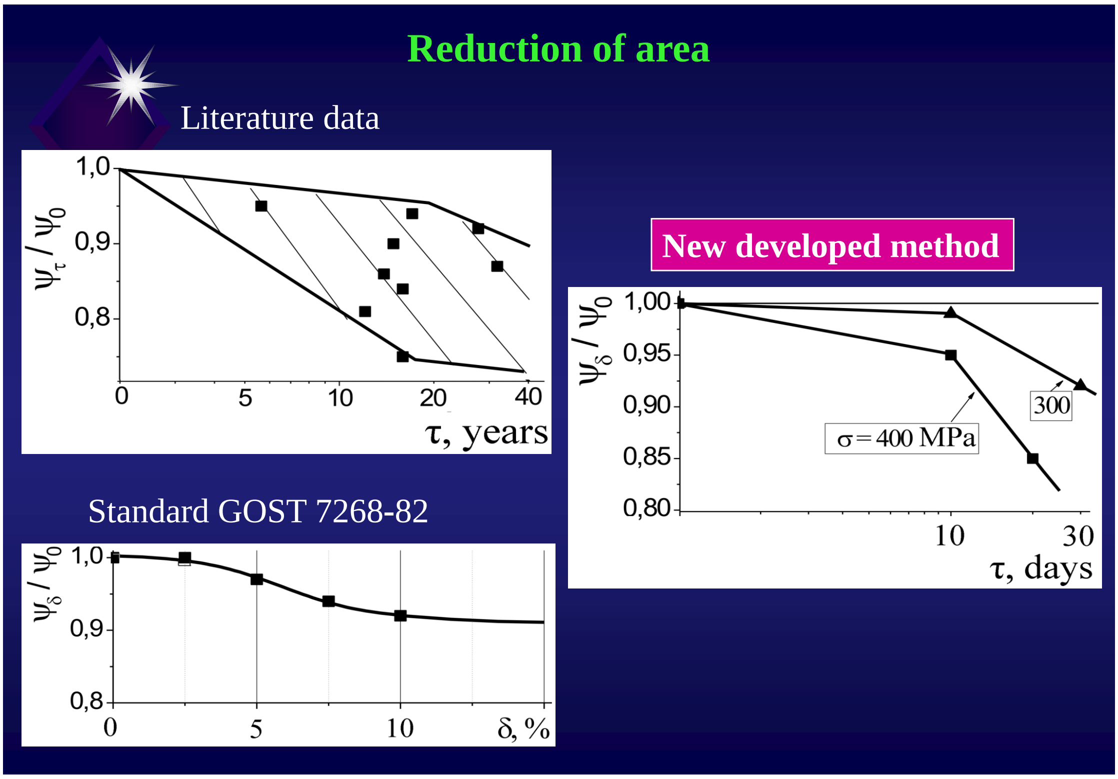
We developed the method which takes into consideration an effect of hydrogen on the degradation process and models a process of dissipated damaging:

Preliminary (electrolytic charging) hydrogenation of specimen;

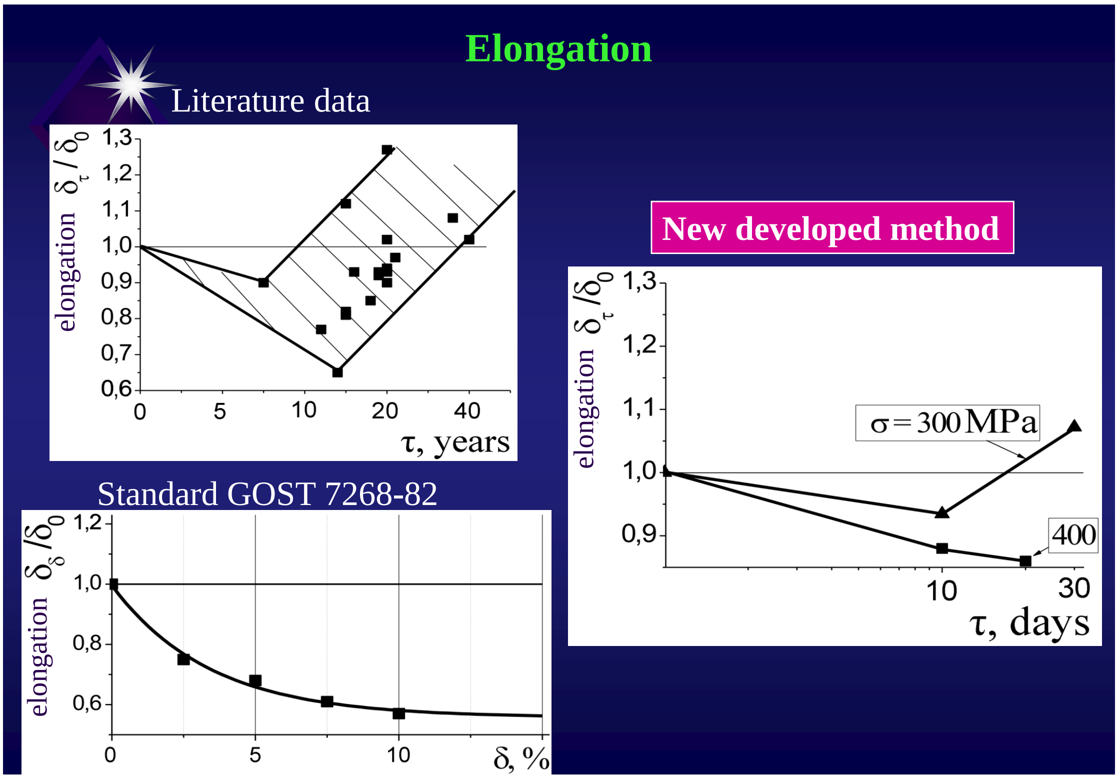
Electrolytic coating of specimen by copper for hydrogen desorption prevention;

Long-term holding (up to 30 days) of specimen under static loading closer to service one;

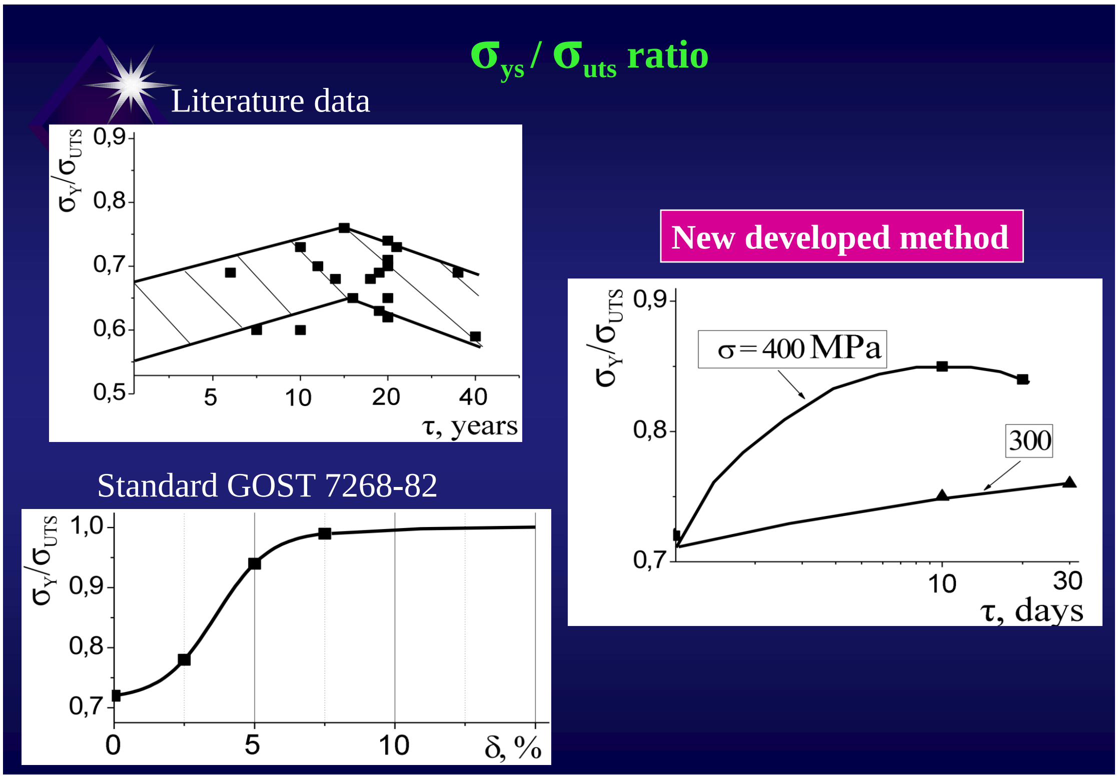
Holding of specimen at 250 °C for hydrogen desorption and deformation aging.

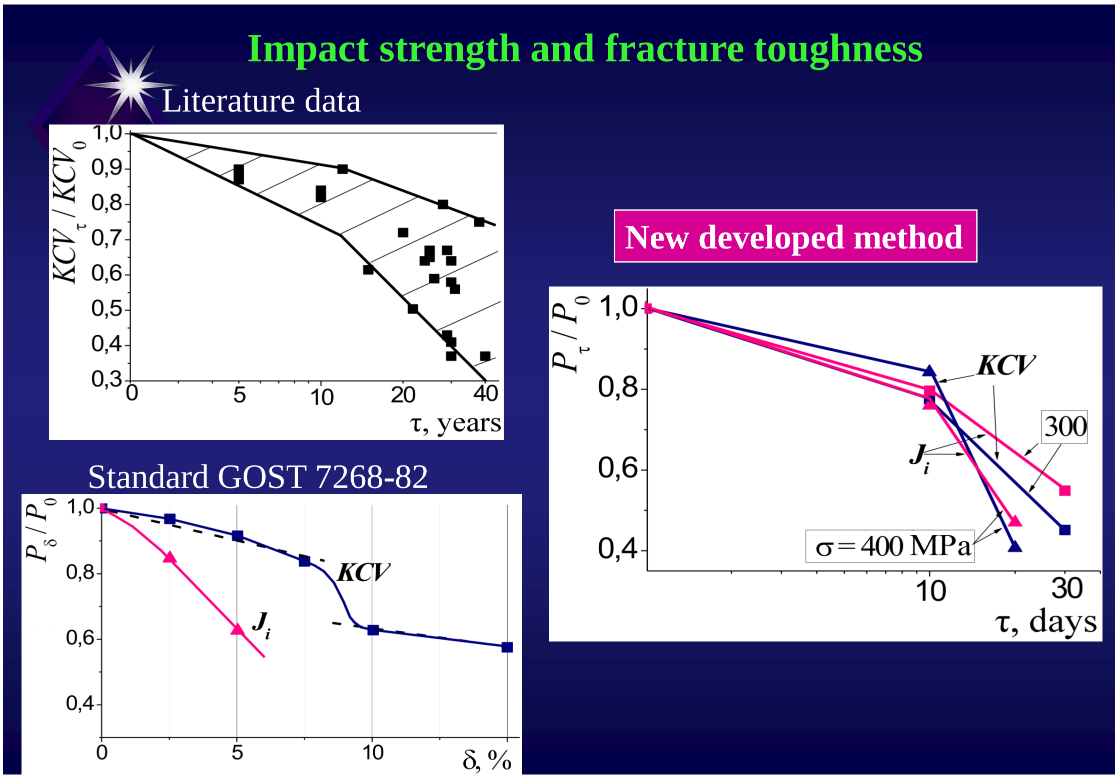


Reduction of area
Literature data
ψ_τ / ψ_0
1,0
0,9
0,8
0
5
10
20
40
τ, years
Standard GOST 7268-82
ψ_δ / ψ_0
1,0
0,9
0,8
0
5
10
δ, %
New developed method
ψ_δ / ψ_0
1,00
0,95
0,90
0,85
0,80
10
30
τ, days
σ = 400 MPa
300



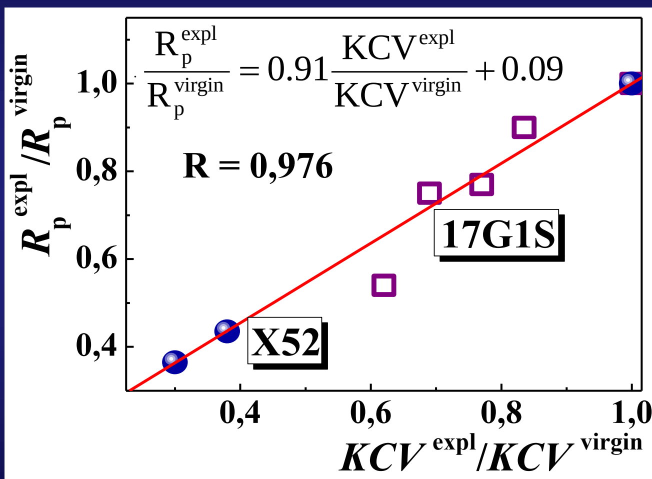
Elongation
Literature data
elongation δ_τ / δ_0
1,3
1,2
1,1
1,0
0,9
0,8
0,7
0,6
0
5
10
20
40
τ, years
Standard GOST 7268-82
elongation δ_δ / δ_0
1,2
1,0
0,8
0,6
0
5
10
δ, %
New developed method
elongation δ_τ / δ_0
1,3
1,2
1,1
1,0
0,9
10
30
τ, days
σ = 300 MPa
400


σys / σuts ratio
Literature data
σY/σUTS
0,9
0,8
0,7
0,6
0,5
5
10
20
40
τ, years
Standard GOST 7268-82
σY/σUTS
1,0
0,9
0,8
0,7
0
5
10
δ, %
New developed method
σY/σUTS
0,9
0,8
0,7
σ = 400 MPa
300
10
30
τ, days

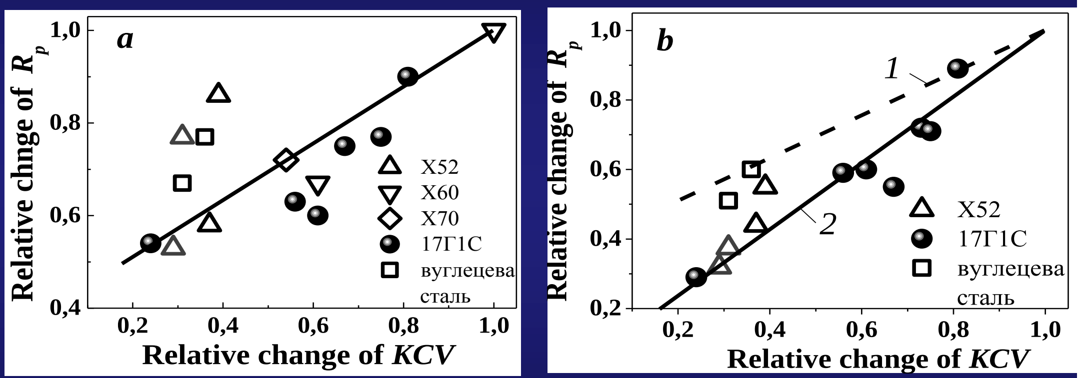

Impact strength and fracture toughness
Literature data
KCVτ / KCV0
1,0
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0
5
10
20
40
τ, years
Standard GOST 7268-82
Pδ / P0
1,0
0,8
0,6
0,4
KCV
Ji
0
5
10
δ, %
New developed method
Pτ / P0
1,0
0,8
0,6
0,4
KCV
300
Ji
σ = 400 MPa
10
30
τ, days

5. Evaluation of in-service degradation by monitoring of electrochemical properties

Correlation between degradation the mechanical (impact strength *KCV*) and electrochemical (polarization resistance *Rp)* characteristics



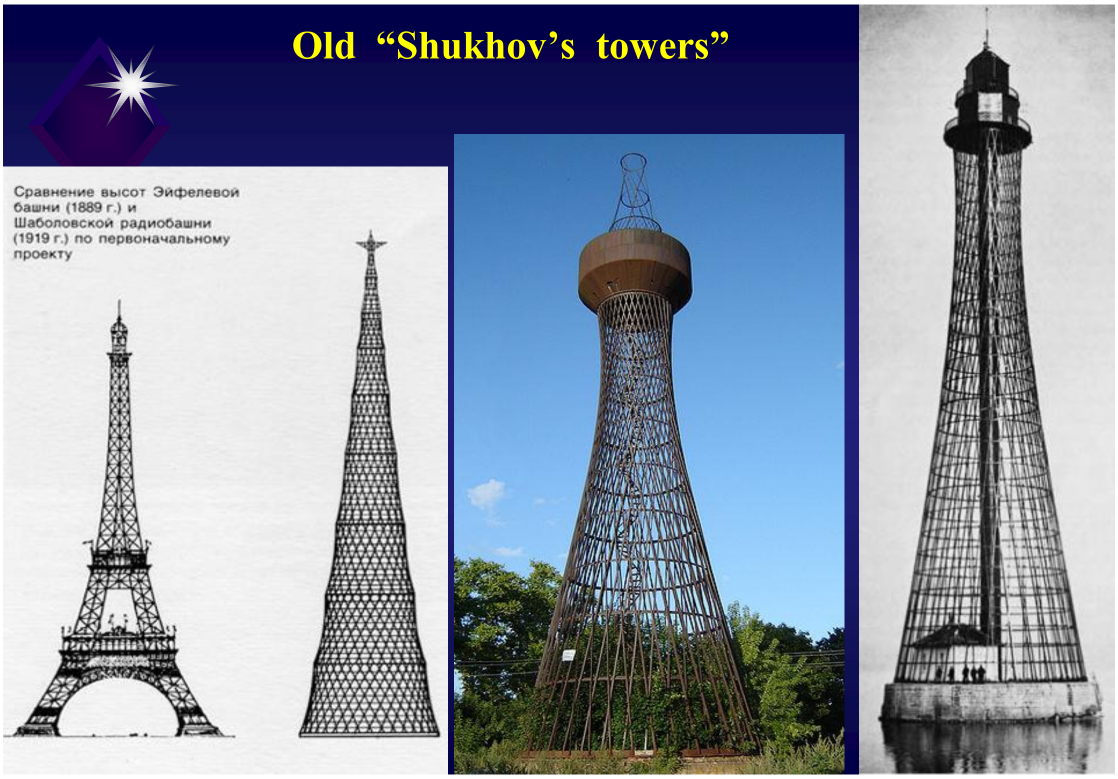
Working environment should not be obligatory used as environment for monitoring of electrochemical characteristics !



6. New challenges in material degradation

The topic for the future Summer School ???

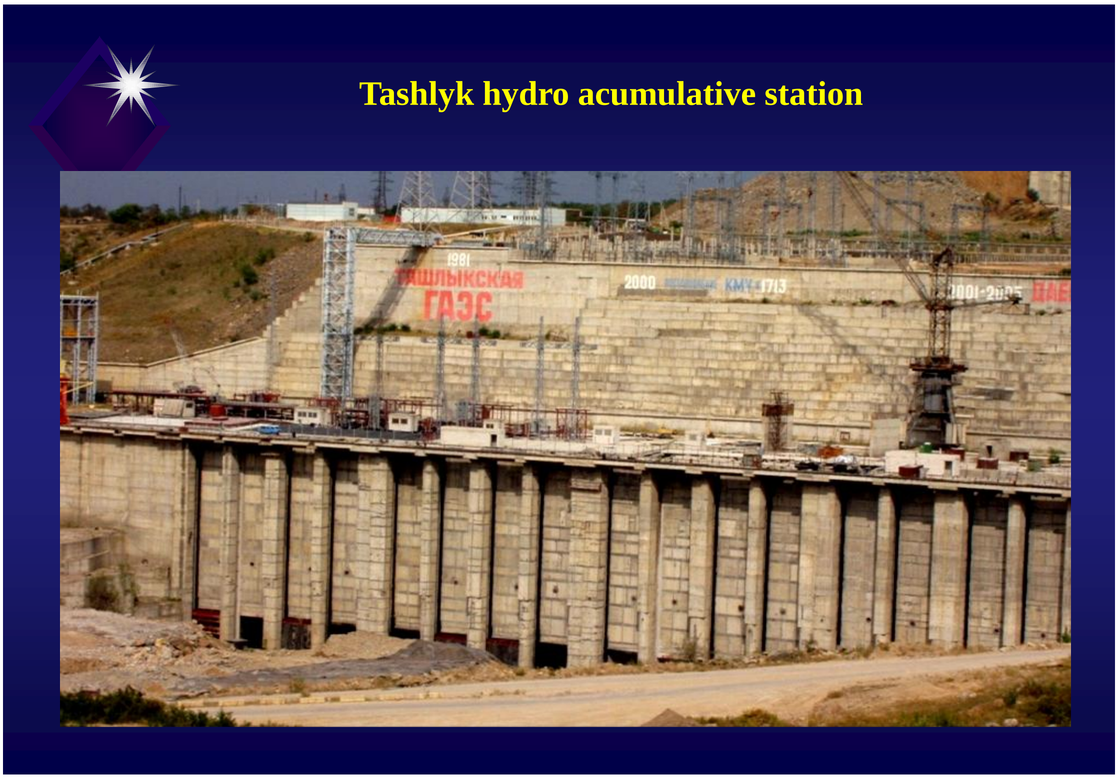

Old Wroclaw bridges
G. LESIUK, M.SZATA, 13th Conference on Fracture Mechanics
September 05 – 07, 2011, Opole, Poland
Materials Science (Springer), 2012
(1861r.)
(1875r.)
(1876r.)
(1885r.)
(1888r.-1889r.)
(1895r.-1897r.)


Old "Shukhov's towers"
Сравнение высот Эйфелевой
башни (1889 г.) и
Шаболовской радиобашни
(1919 г.) по первоначальному
проекту

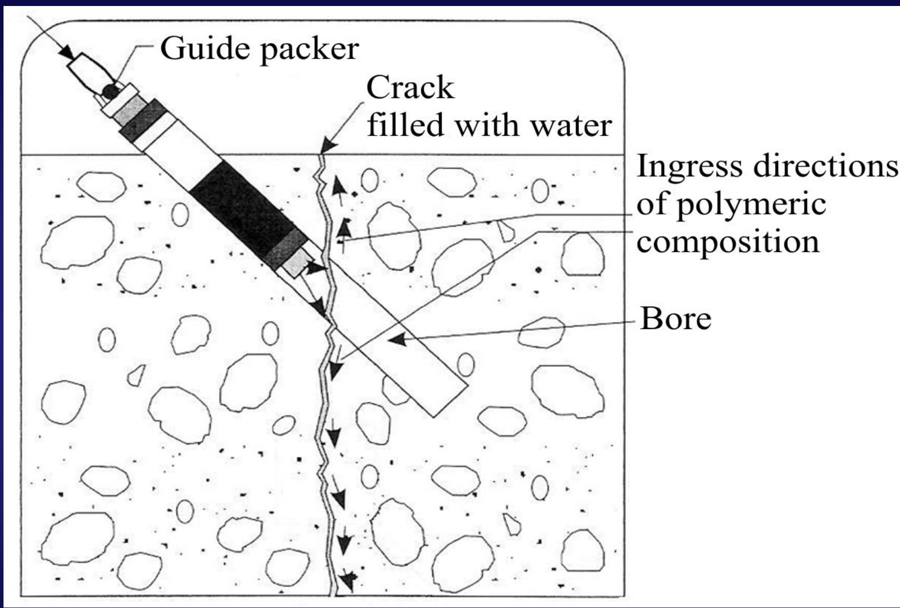
Degradation of concrete and reinforced concrete

Damaged bridges


C13
C14


Tashlyk hydro acumulative station
1981
ТАШЛЫКСКАЯ
ГАЭС
2000
2001-2005

The scheme of injection technology



The problem involves material science, corrosion and mechanical (fracture mechanics) aspects

7. Conclusion

Thank you for your attention!

Dziękuję za uwagę !

Danke für Ihre Aufmerksamkeit!

Дякую за увагу!