Inspection guidelines and determination of reasons for failure of flue gas ducts and stacks of fibre-reinforced plastics

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KIMAB

Swerea KIMAB is one of the oldest Swedish research institute, founded 1921 and it is a merge between the Swedish corrosion institute and the institute for metal research

Gunnar Bergman started the polymer group in 1981

Polymeric materials

Karin Jacobson
Group leader

Daniel Ejdeholm
Research leader

Nina Pendergraph
Researcher

Klas Esbo
Researcher

Love Pallon
Researcher

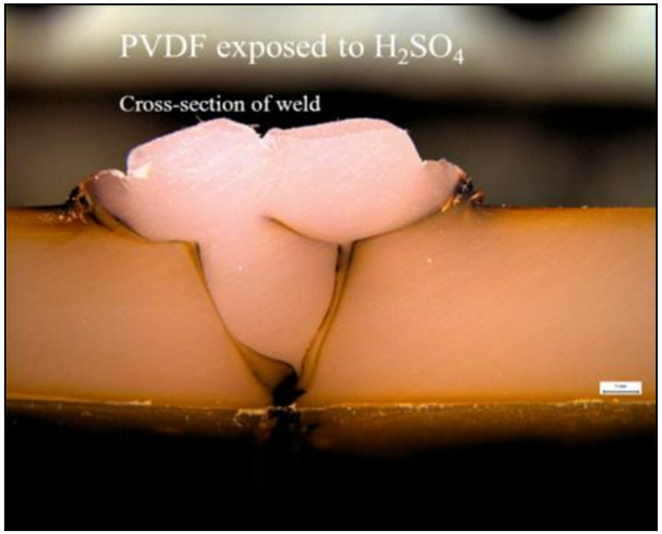
Martina Källrot Janstål
Researcher

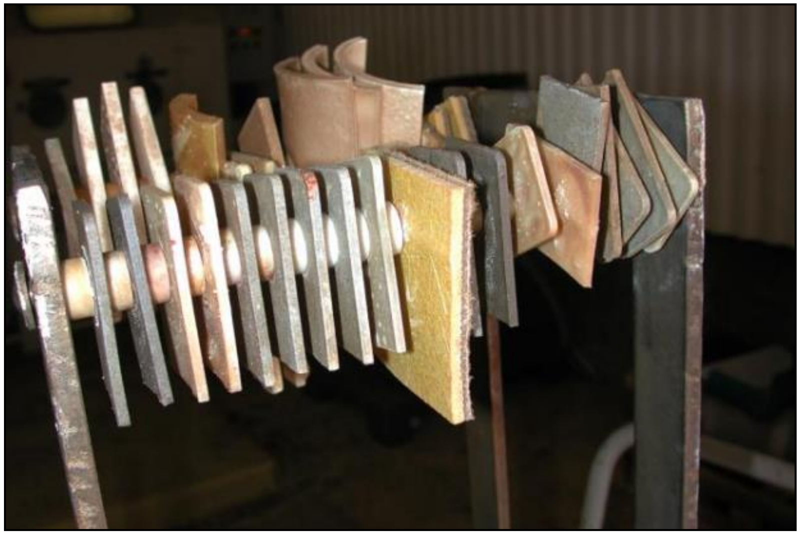
Dinko Lukes
Researcher

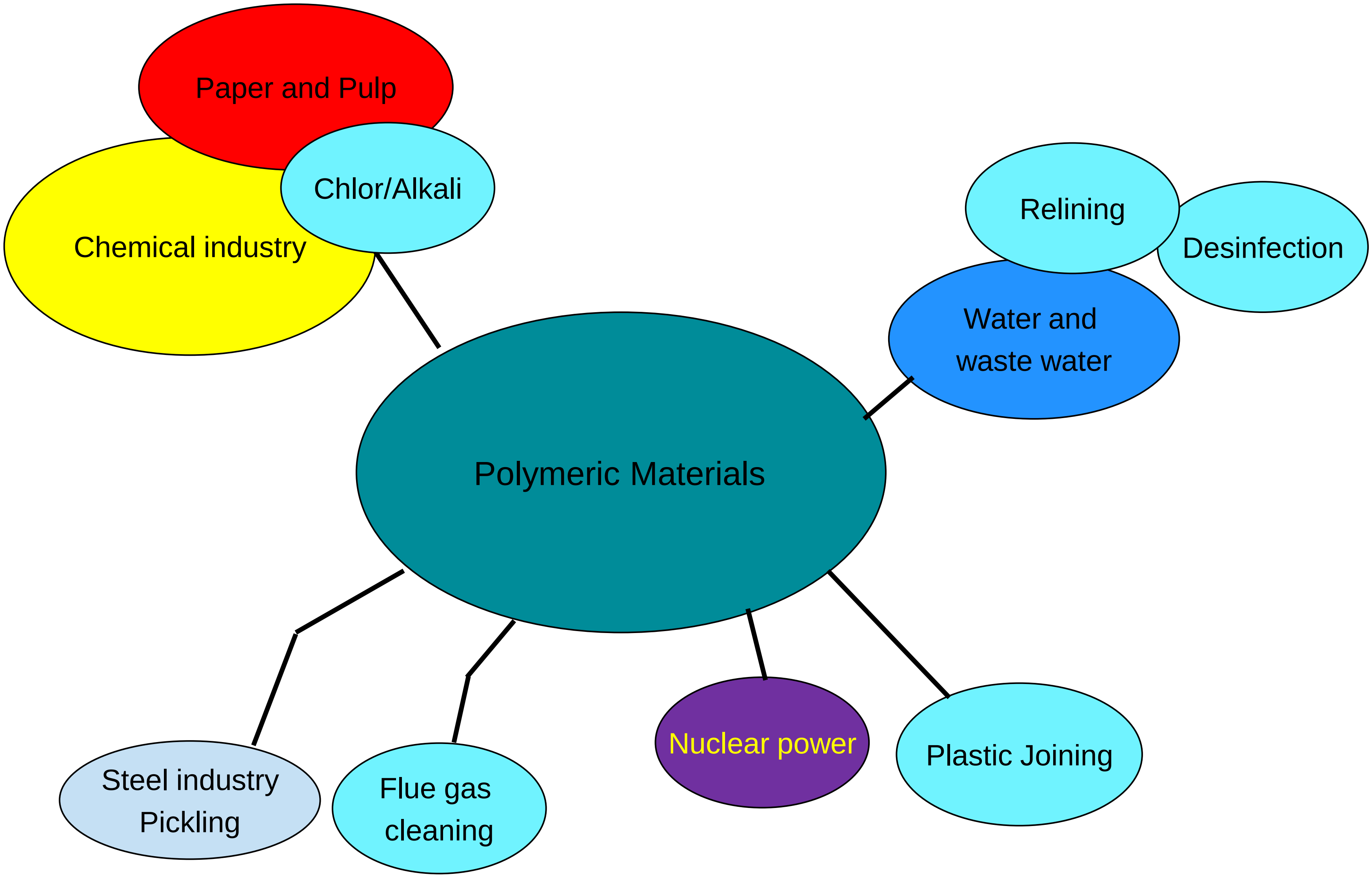
Johanna Josefsson
Trainee

Our expertise – Need driven industrial research

- Member program: Polymeric Materials in Corrosive Environments
- Approximately 30 members
- From producers to end users
- Main focus areas are chlorine production, sulphuric acid, flue gas cleaning **and** pulp and paper production
- We are also active in a number of research projects and do contract work, material recommendations, ageing studies and exposures in harsh environments (H_2SO_4, HF, ClO_2, spent acid, chlorine….)





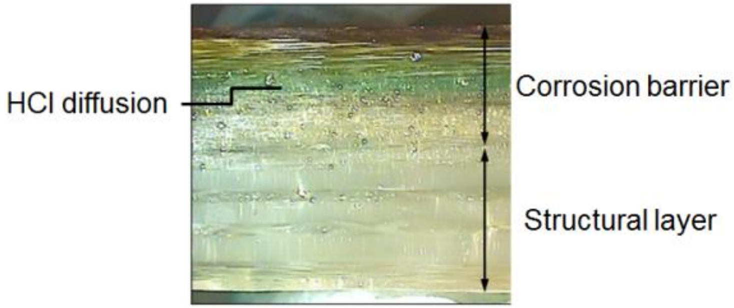

Paper and Pulp
Chlor/Alkali
Chemical industry
Relining
Desinfection
Water and waste water
Polymeric Materials
Steel industry Pickling
Flue gas cleaning
Nuclear power
Plastic Joining

Agenda

- Damage modes of FRP – a Handbook
- Inspections
- Investigation of flue gas stacks
- KIMAB’s “in-house flue gas stack”

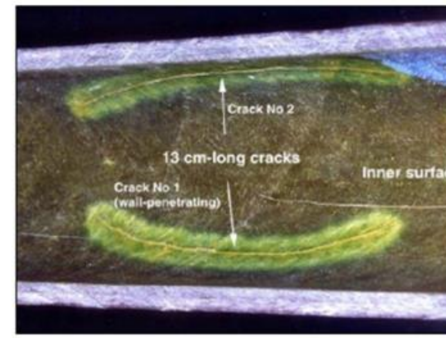
Damage modes of FRP

Diffusion

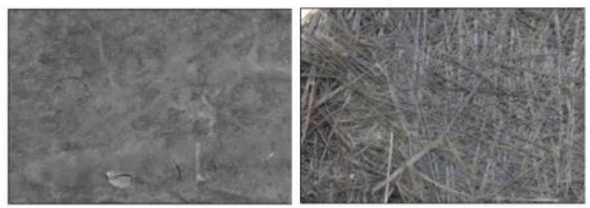


Blisters

Stress corrosion cracking



Discoloration



Delaminations

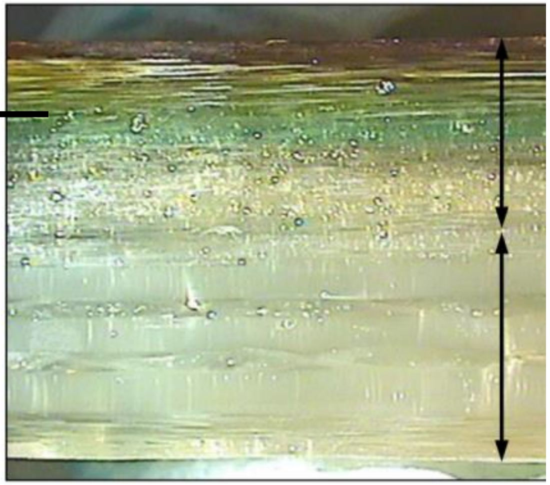
Cracks

Surface cracks | Drying cracks | Structural cracks

Diffusion

- FRPs are permeable
- Diffusion of the corrosive media into the corrosion barrier is okay, but never into the structural layer
- Microscopy analysis of a polished cut-out can be an efficient tool to determine the diffusion

HCl diffusion



Corrosion barrier

Structural layer

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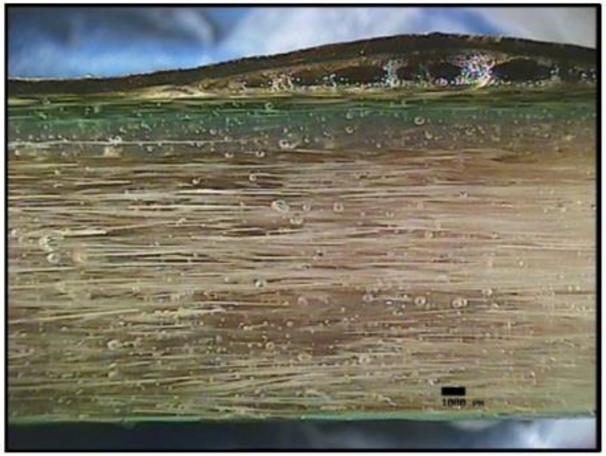
Blisters

- A combination of diffusion and an osmotic pressure
- In general they are superficial and situated close to the surface



Delamination

- Often due to thermal stress
- In general more severe than blisters
- Can often be repaired

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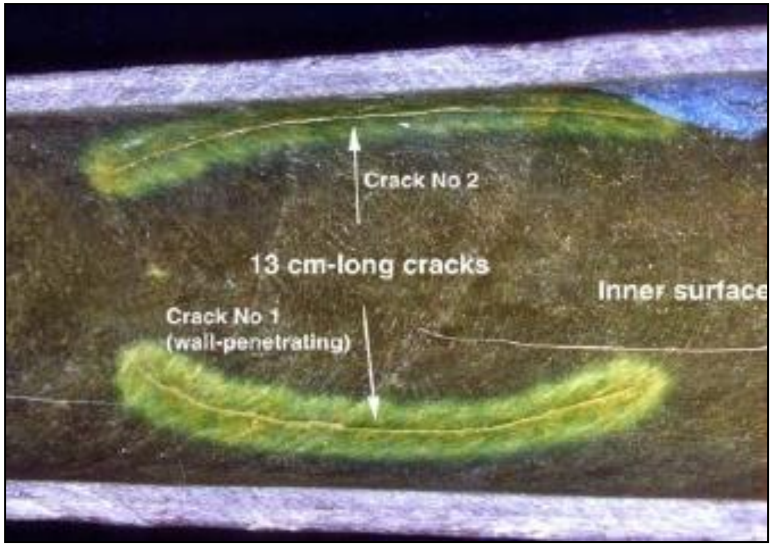
Stress corrosion cracking

- A combination of chemical attack and stress on fibers
- Rapid and dangerous raptures
- Impact damage can be a starting point for failure

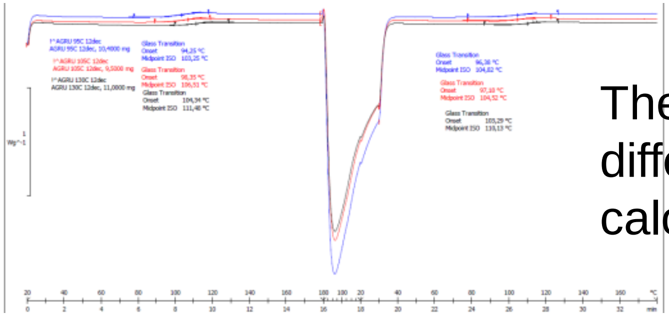


Inspections

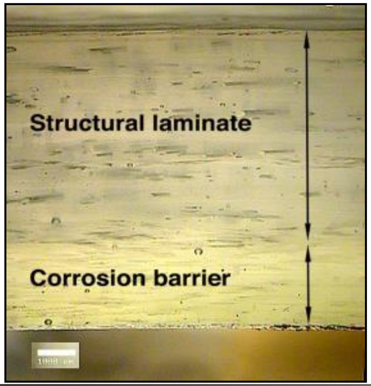
Destructive testing

Composition

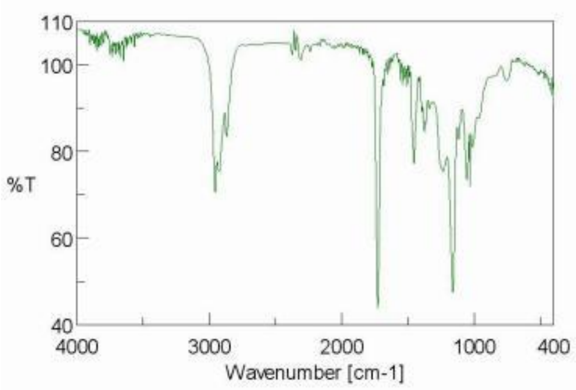
Mechanical strength



Thermal history by differential scanning calometry (DSC)



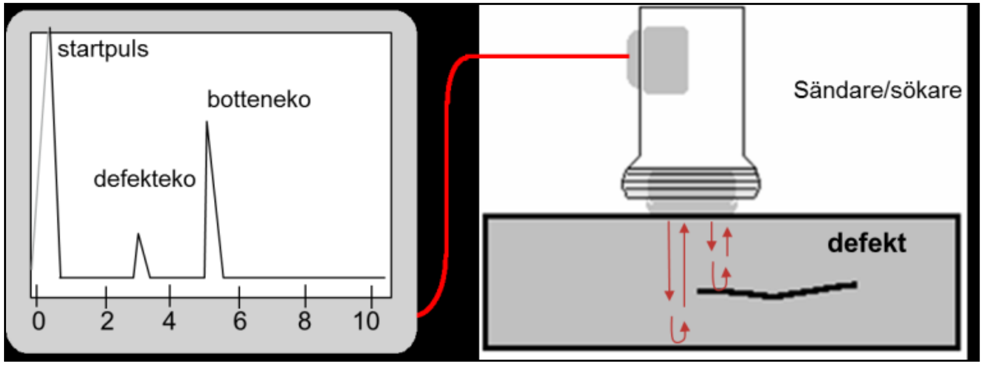
Microscope

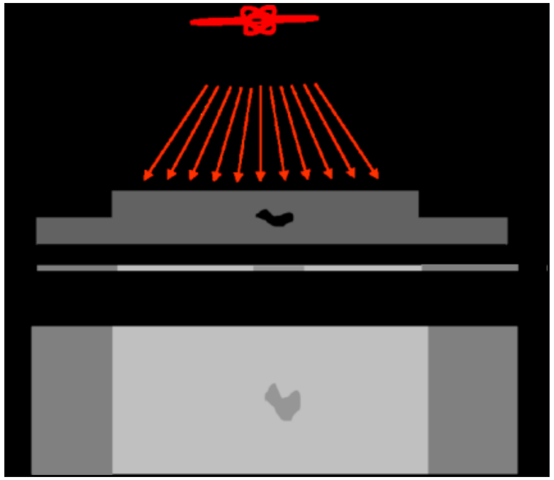


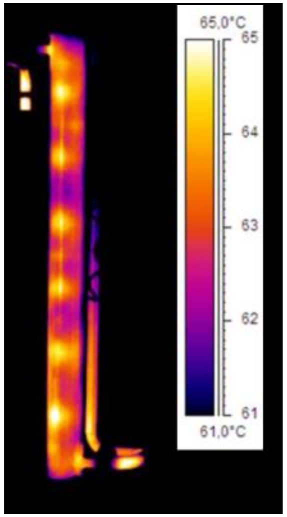
Chemical composition by Fourier Transform Infrared Spectroscopy (FTIR)

Non-destructive testing

- Visual inspection
- Ultrasound
- X-ray
- Acoustic emission
- Barcol Hardness



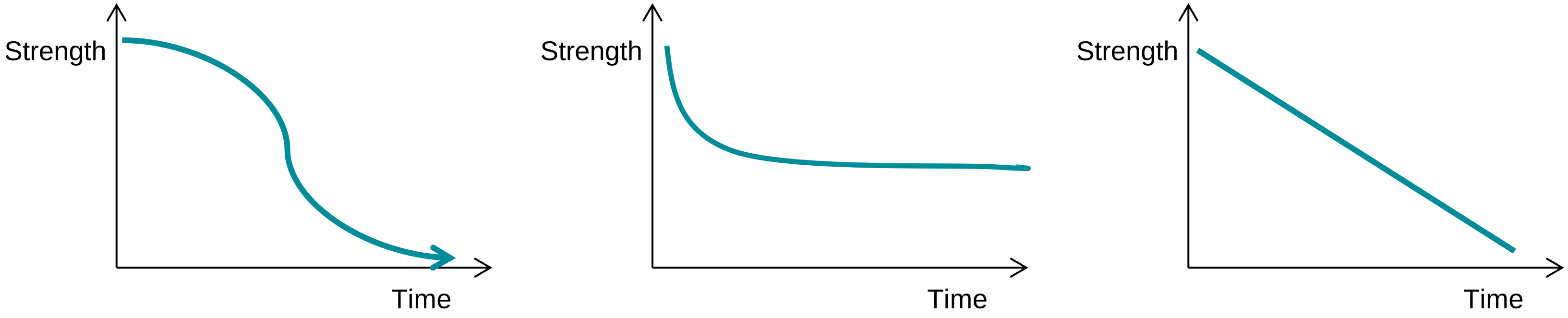




Investigation of flue gas stacks

Fitness for service

- What are the limiting factors when the chemical conditions are mild?
- How will the mechanical properties change during the service life?



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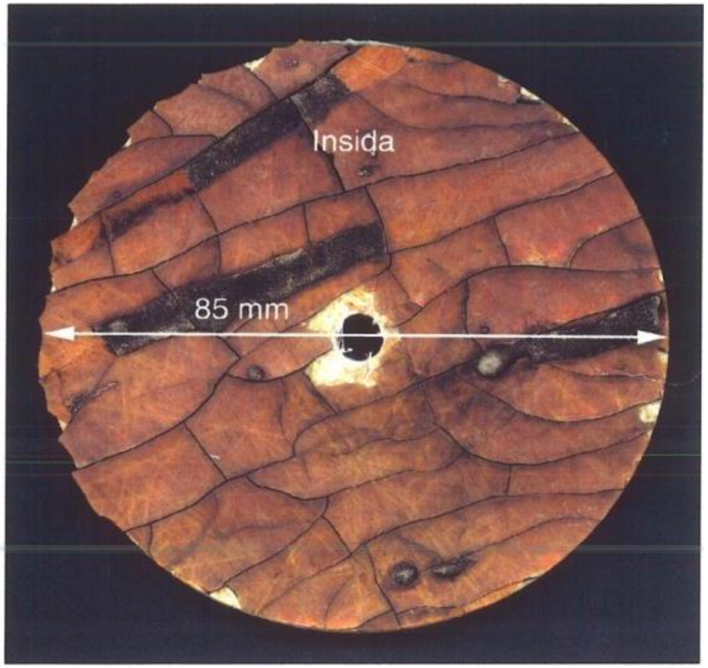
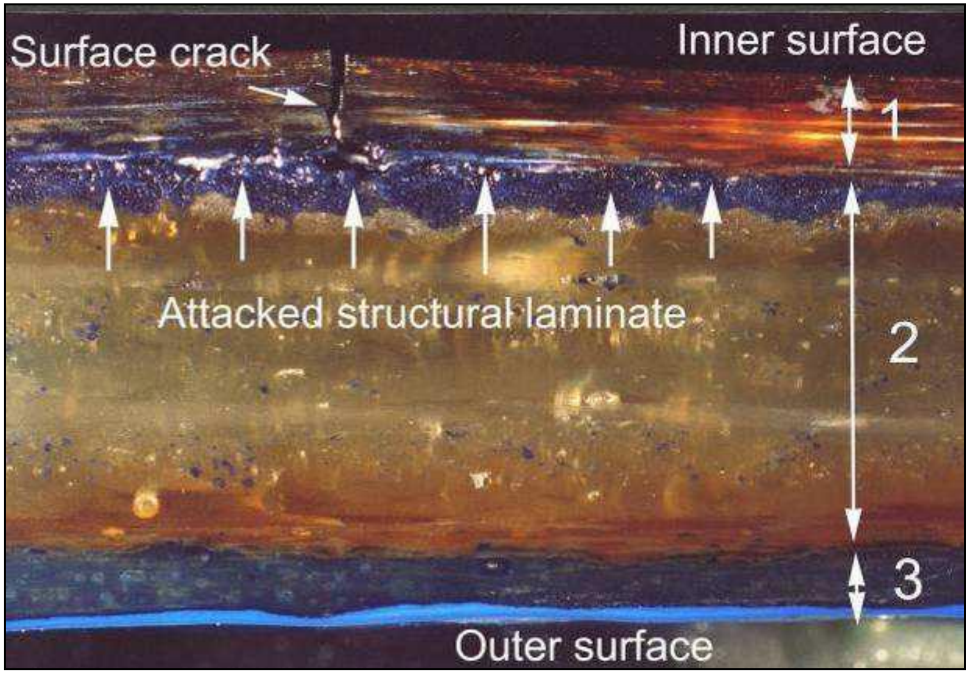
45 year old flue gas stack

- The stack was originally 40 m high
- Elongated (1985) to 68 m
- The diameter is approx. 3.6 m.

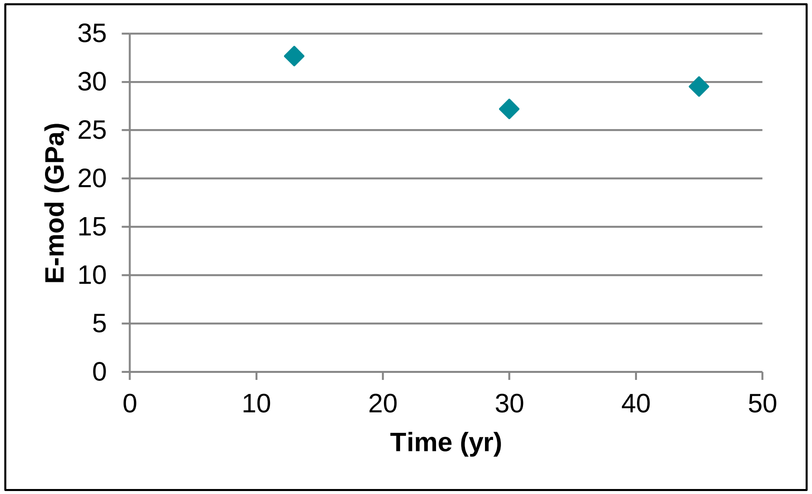




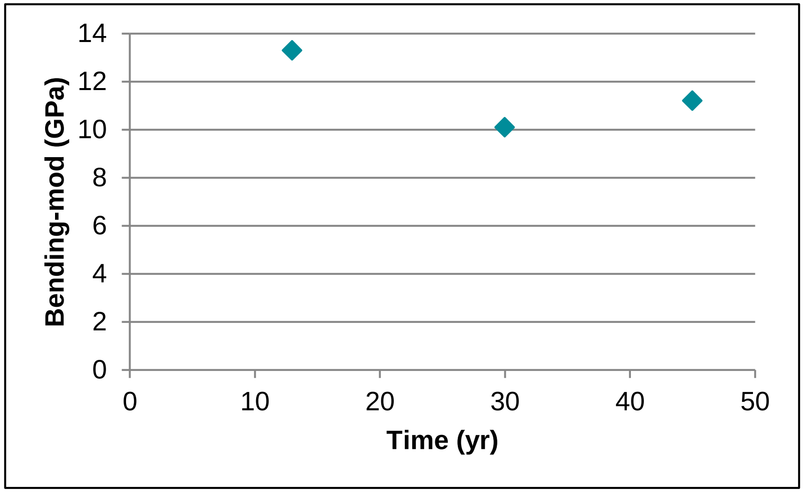
Severely attacked

45 year old flue gas stack
- Mechanical properties

Tensile modulus



Flexural modulus



Only a slight decrease in modulus!

(The deviations between 30 and 45 years could be due to misalignment in fiber direction for the sample cut-out)

Investigation

- 8 flue gas stacks were investigated according to their reduction in the elastic modulus (E-modulus)

- The reduction was determine by comparison of destructive tensile test and the optimal theoretical E-modulus, which was calculated by classical lamination theory

- The damage modes of the stacks were predominately surface cracks and deeper cracks

- The stacks were probably designed with a safety factor of 10

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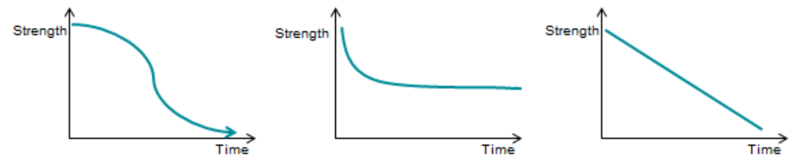
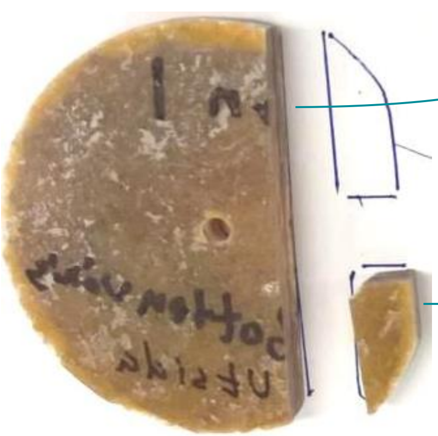
Method



How to measure the reduction ?

KIMAB's approach:



Destructive tensile tests

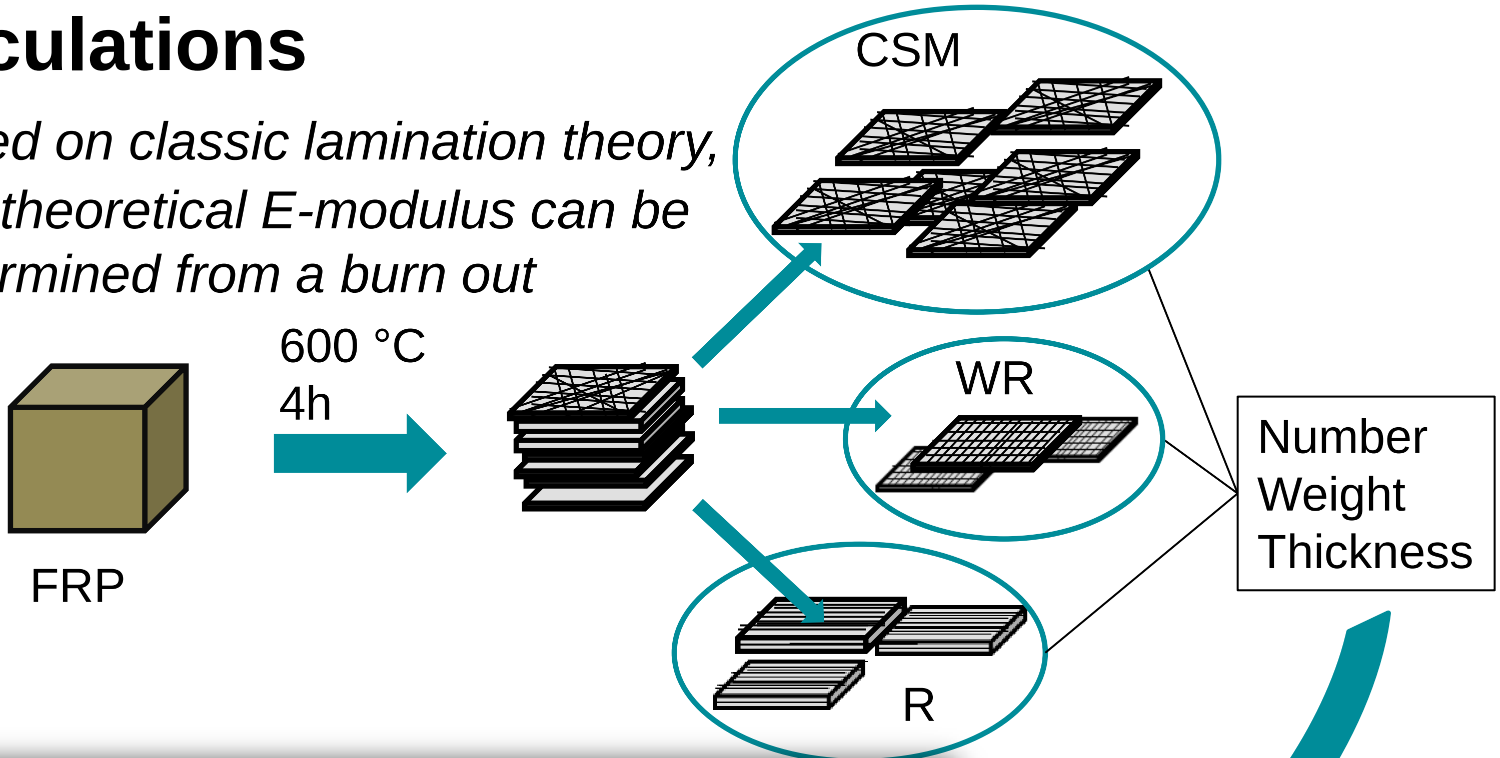
Burn out
+Calculations

$$\frac{\text{Current E modulus}}{\text{Theoretical E modulus}} = \text{PDS}$$

(Percent of design strength)

Calculations

-*Based on classic lamination theory, The theoretical E-modulus can be determined from a burn out*



Density			
ρ r	1140,0	kg/m^2	densitet resin

The samples dimensions			Notes
Length	25,72	mm	Average
Thickness	21,69	mm	Average
Height	7,99	mm	Average

The glass fibres dimmensions			Nr
Thickness of CSM	0,3	mm	5
Thickness of WR	0,65	mm	1
Thickness of R	1,2	mm	2

The samples weight			Notes
Weight of melting pot	25,2	g	
+ the sample	31,8	g	
After the burn out	28,2	g	

The glass fibres weight			Notes
Weight of CSM	0,68	g	
Weight of WR	0,35	g	
Weight of R	1,94	g	
Tot	2,97	g	

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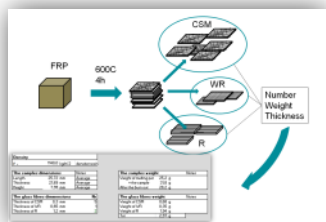
Calculations



$$t_i = \left(\frac{1}{\rho_g} + \frac{(100 - m_g)}{m_g \cdot \rho_r} \right) \cdot 10^3$$

	S-glas	C-glas	E-glas
ρ_g	2530	2560	2540

ρ_r	1140	kg/m^3	densitet resin	
E resin	4000	MPa	modul resin	
	CSM	WR	Roving	
U_i	200	250	500	(N/mm)/(kg/m2 glass) Ultimate tensile unit strength per layer i
X_i	14000	16000	28000	(N/mm)/(kg/m2 glass) Unit modulus per layer i

Area	
Average area	557,877 mm^2

Volume		
Volume tot.	4454,65 mm^3	4,45 cm3
Volume glas	1,17 cm3	26,3 vol%
Volume resin	3,28 cm3	73,7 vol%

Weights		
Weight of the sample	6,618 g	
Weight of the glass	3,0 g	
Glass content	44,9 wt%	
Resin content	55,1 wt%	
Check	0,002	Should be close to zero

Density		
ρ_r	1109,7 kg/m^2	density resin

	CSM	WR	Roving	Unit	Notes
m_g	50	60	75	% g/g	Weight content of each glass
t_i	1,27	0,98	0,69	mm	Theoretical thickness in order to create 1kg glas/m2
m_i	0,245	0,626	1,739	kg/m2	Weight of glass per area (typical values 225, 450, 600 g/m2)
n_i	5	1	2	Nr	
Calculated thickness	0,31	0,61	1,19	mm	Calculated thickness of one layer
Meassured thickness	0,3	0,65	1,2		Meassured thickness

$U_{lam,k}$	2140	(N/mm) Ultimate tensile unit strength fot the laminate
$X_{lam,k}$	124519	(N/mm) Ultimate modulus for the laminate
t	4,55	(mm) Thickness of the glass

S	470	(MPa) Strength
E	31343	(MPa) E-modulus

Youngs modulus

Example

Resin	Atlac 382-05

(PDS=Percent of design strength)

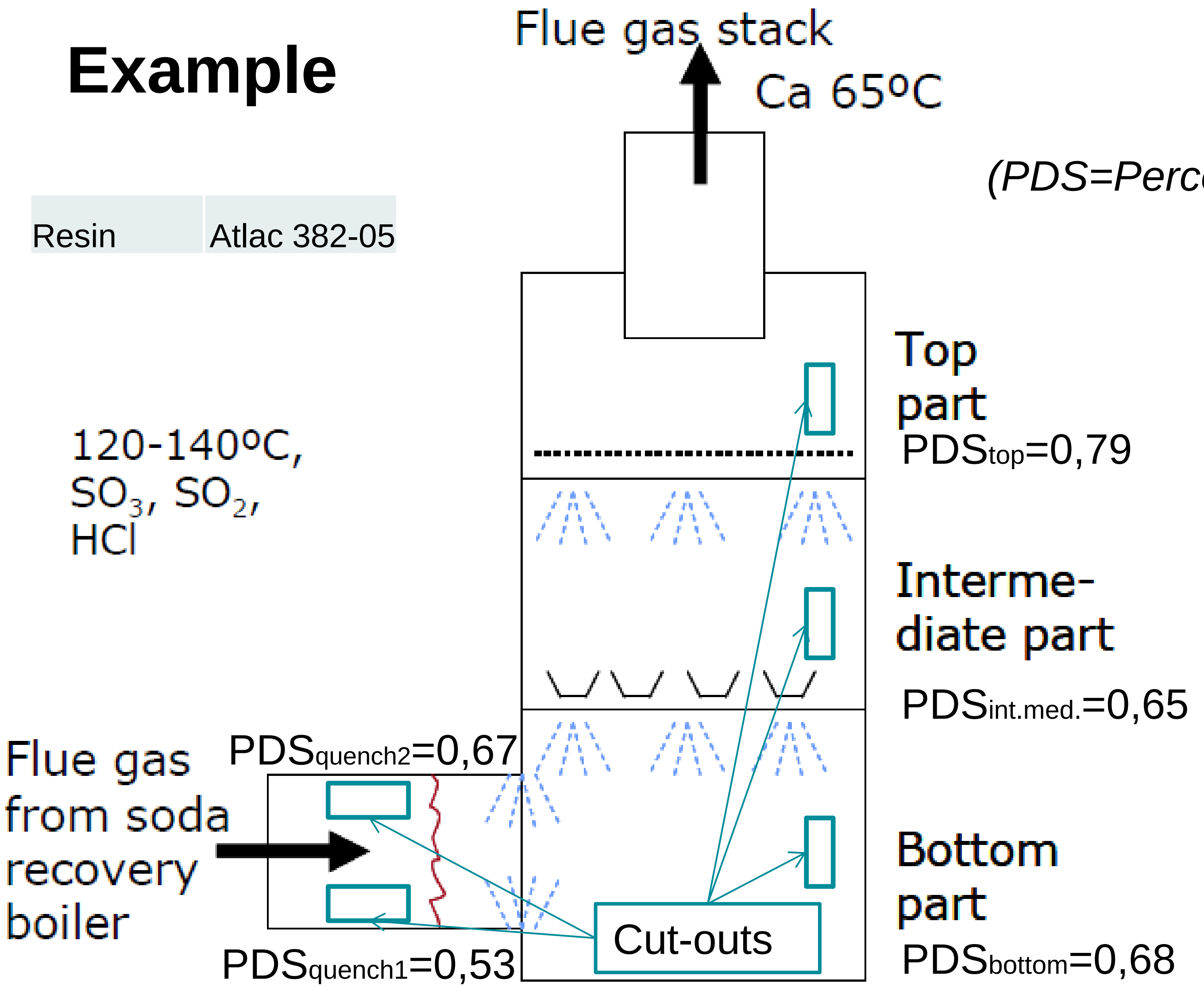
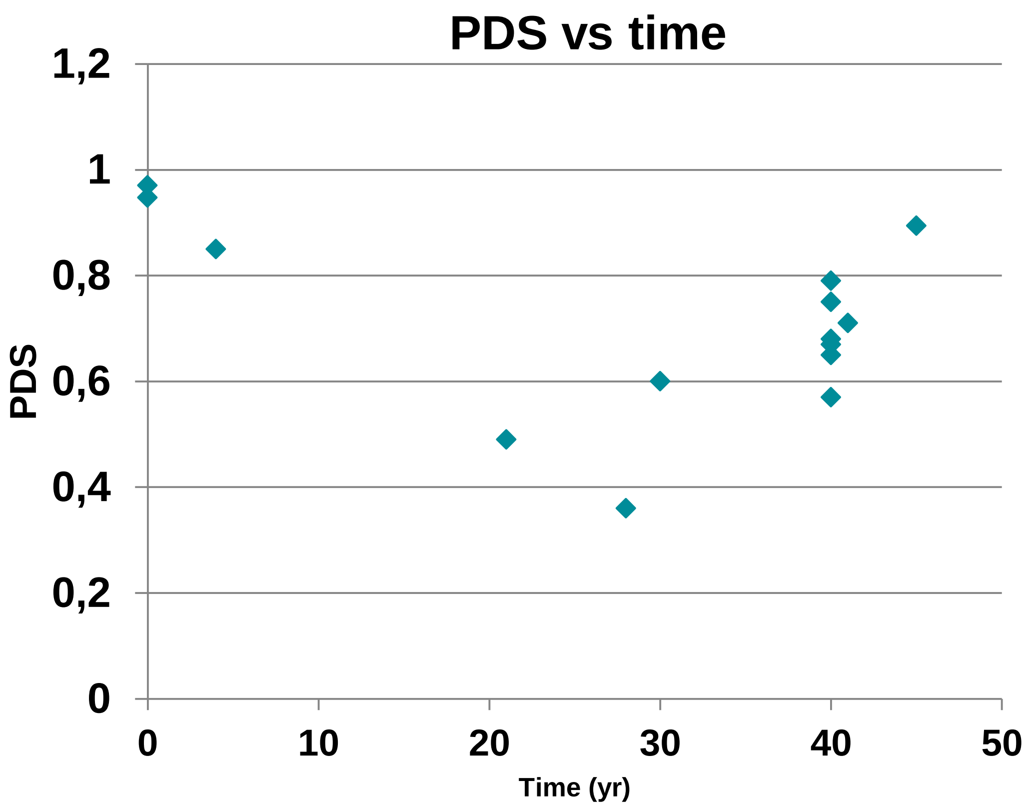


Figure 59. Surface cracking in non-repaired laminate (at a manhole), i.e. 30-year-old laminate, from the bottom part of the scrubber.

Result



<u>Observations</u>

- KIMAB's approach correlates well with the observations from the microscope analysis, and thereby enables remaining service life determinations

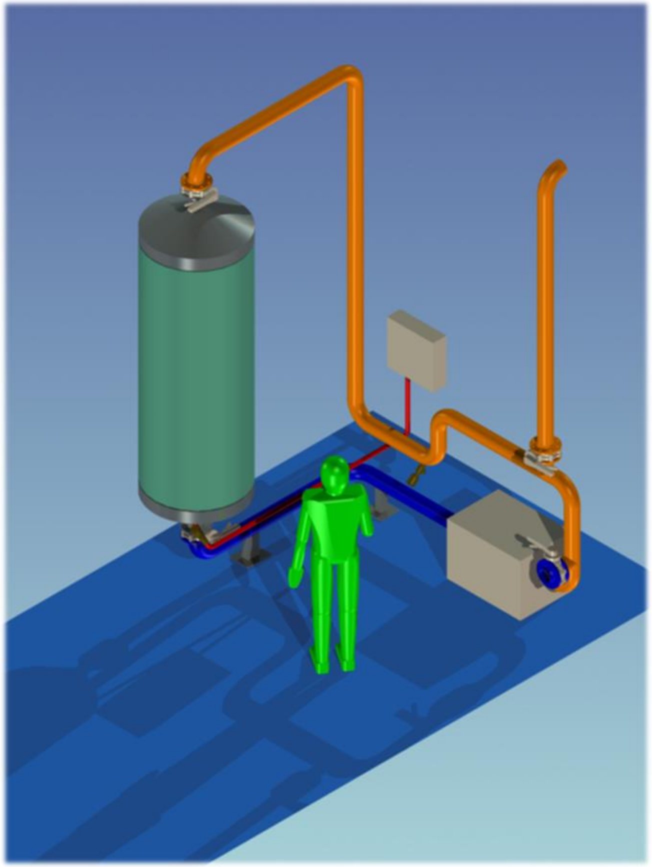
- As long as no severe damage modes can be seen, the reduction in E-modulus is limited

New project, In-house "flue gas stack"

- What about other losses in material properties?
- Delaminations, a reason for concern
- Can we provoke delaminations by rapid heating?
- Need for deeper understanding of the mechanisms behind delamination
- Previous experiments with unrestricted test piece failed to provoke delamination

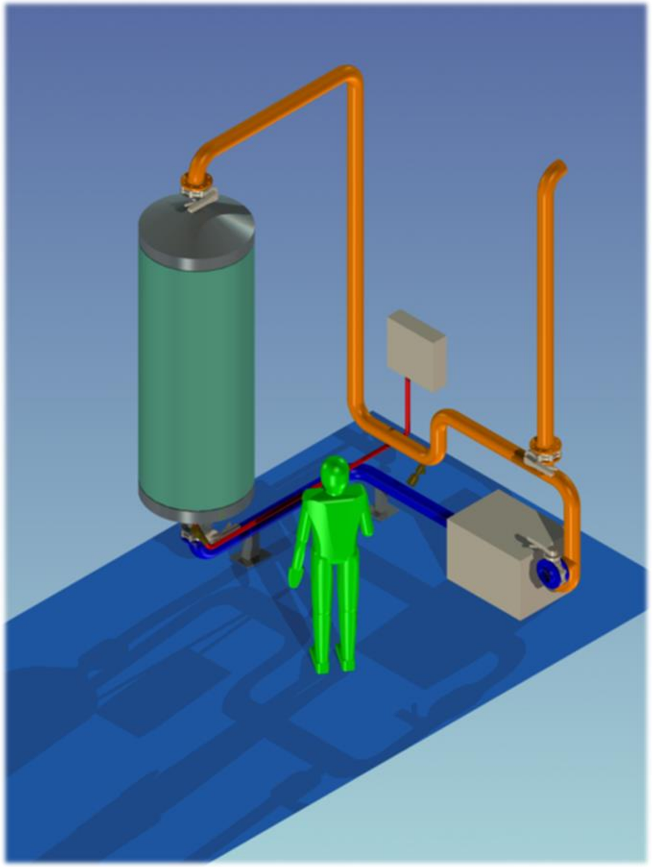
Continuation – New project, in-house ”flue gas stack”

- Test pieces with restricted expansion
- Industrially produced laminates
- Downsizing
  - Diameter ≈ 0.4 m
  - Height ≈ 1.5 m
- Simulated by-pass operation
  - 60 °C and 98% RH
  - 200 °C
- 20 kW heating, 20→200 °C in 8 s
  - Thermal chock – to stimulate stresses
- High convection of air, 10 m/s in the stack
- Longtime cyclic exposure



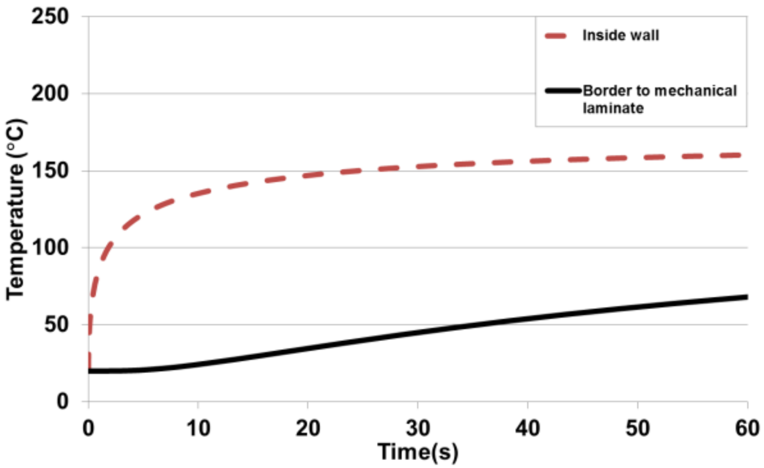
Continuation – New project, in-house ”flue gas stack”

- Possibility to evaluated materials before full scale construction
- To understand the mechanism behind delamination
- Online monitoring with sensors possible

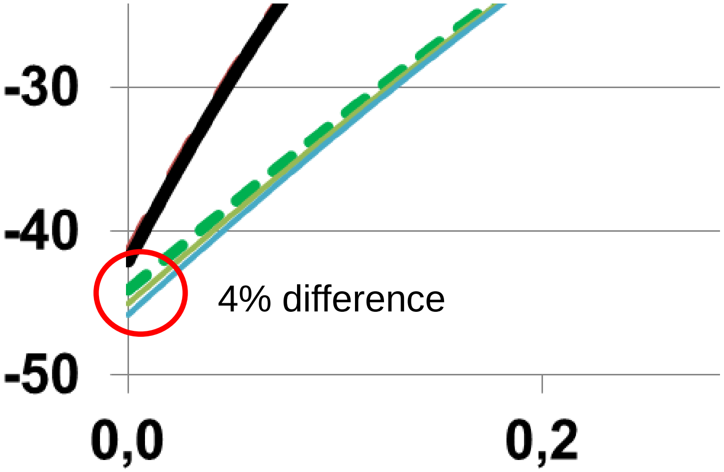


Calculations on downsizing

Temperature gradient



Hoop stress



- Corrosion layer – 3.5 mm, mechanical laminate – 6.5 mm
- At a diameter of 300 mm hoop stress starts to deviate from real conditions
- Possible to retain wall thickness of an original stack

*Calculations made by Erik Marklund, Swerea SICOMP

New possibilities

- Screening of materials
- Effect of insulation
- Online monitoring with coupled sensors
  - Acoustic emission
  - Infrared camera
  - Lamb waves

- Your suggestions on FRP build-up and monitoring techniques to be tested are most welcome!

Thanks to our members!

Accoat A/S	INOVYN/Solvay Specialty Polymers SpA
AGRU Kunststofftechnik GmbH	Kemira Kemi
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Akzo Nobel Pulp and Performance Chemicals AB	Lyma Kemiteknik
Aliancys Nederland B.V.	Nordpipe Composite Engineering Oy
Ashland Technologies GmbH	Plasticon Germany GMBH
Covestro Deutschland AG	Polynt Composites Norway
Dow Chemical	SABIC Innovative Plastics
FIP SpA Formatura Iniezione Polimeri	SIMONA AG
Flowtite Technology AS	Steuler Nordic
Georg Fischer DEKA Gmbh	Tekniska verken i Linköping
Glencore Nikkelverk AS	Termap
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