MARITIME

Numerical simulation for thermo-mechanical analysis within alternative design

Pavel Golyshev

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FIRE-RESIST

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SAFER, SMARTER, GREENER

Content

- Introduction & Motivation
- Thermo-mechanical analysis used in alternative design
- Description of CFD-FEA simulation concept
- Example application: maritime case study of the Fire-Resist
- Summary & Conclusion

Introduction & Motivation

- Fibre reinforced plastic (FRP) is an interesting material for maritime industries because of:
  - weight-strength relation (reduced structural weight),
  - efficient fabrication of complex shapes (moulding freedom),
  - low affinity of corrosion etc.
- Usage of FRP is limited by its fire behaviour, i.e. typically in fire FRPs tend to react exothermic and loose their form stability
- As a consequence, the usage of FRPs in ship building is limited by current regulations, e.g. to:
  - Parts permitted to have lower fire resistance
  - Ship types with limited service range (-> High Speed Craft)
- Only possibility for using FRPs in other areas: demonstrate **safety equivalence**!

→ IMO Alternative Design (MSC.1Circ.1455, 2013)

Introduction & Motivation

- Important characteristics to be considered for demonstrating safety equivalence
  - Smoke
  - Toxicity
  - Fire resistance / flammability
  - SOLAS functional objectives

1.1 The fire safety objectives of this chapter are to:

.1 prevent the occurrence of fire and explosion;

.2 reduce the risk to life caused by fire;

.3 reduce the risk of damage caused by fire to the ship, its cargo and the environment;

.4 contain, control and suppress fire and explosion in the compartment of origin; and

.5 provide adequate and readily accessible means of escape for passengers and crew.

- For complying with this functional objective
  - Temperature conductivity needs to be limited (controlled)
  - **Bulkhead needs to be intact as a fire barrier**

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Fire-Resist

- EU project in FP 7 2011 – 2015 by
- Partners: **ACG, AMORIM, AP&M, APC, BAL, Bombardier, EADS, FSG, Gaiker, INSA, Proplast, SICOPM, SP, Steinbeis R-tech, VTT**
- Selected objectives
  - Develop new reinforced plastic materials with increased fire resistance
  - Develop tools for numerical simulation of structural fire behaviour
- Numerical simulation allows
  - Detailed investigation of the behaviour of structures in fire, e.g.
    - Temperature distribution
    - Thermal strains and stresses
    - Remaining load bearing capacity

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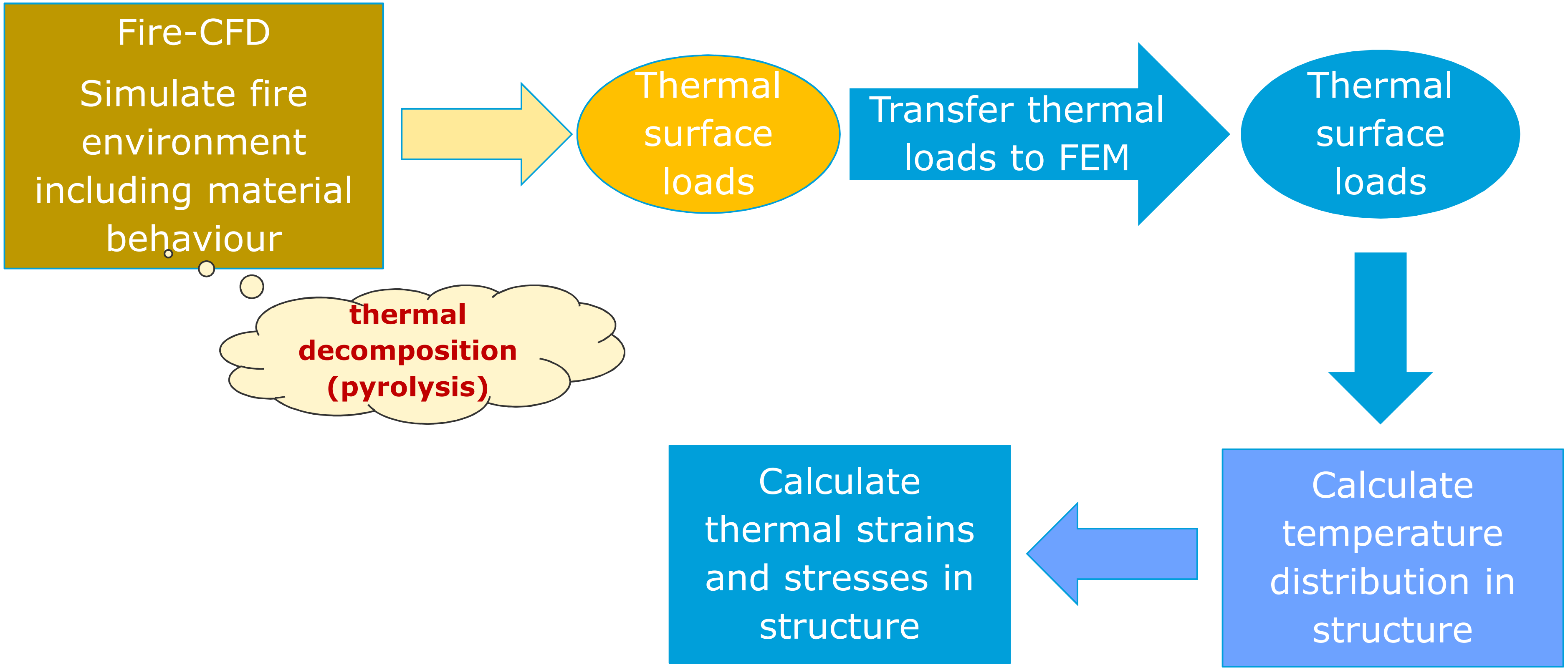
Thermo-Mechanical Simulation Concept



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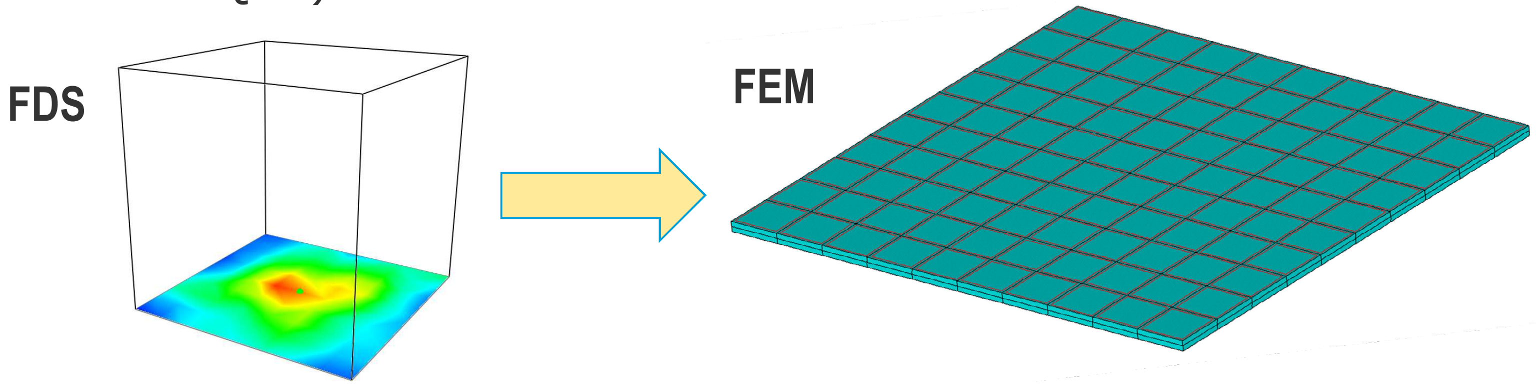
Fire Simulation

- Simulation carried out using Fire Dynamic Simulator (FDS)
  - Coupled sub-models for calculating
    - Fluid dynamics
    - Gas phase chemical reactions
    - Radiation
    - Solid phase heat conduction
    - Pyrolysis -> central role in the simulation of combustible materials
- For simulation of FRPs, needed parameters
  - Directly measured
  - If not possible: small scale test, e.g. kinematic parameters for approximating temperature dependent rate of thermal decomposition were determined via thermo-gravimetric analysis
    (measure the mass loss and heat release rate)

Thermo-Mechanical Analysis

- Finite Element technique offers the possibility to solve the thermo-mechanical problem, i.e. temperature distribution and related strains
- Typically for problems with negligible small heat release by mechanical deformation => one-directional coupling (thermal -> mechanical)
  - Calculate time dependent temperature field in the structure based on the thermal loads determined by FDS
  - Calculate thermal strains and related stress considering also other external loads if any
- For this process: Routine developed for mapping FDS thermal loads to FE model (ANSYS and ABAQUS)



Proposed concept

- Part/ wall of Ro-Ro cabin
- Wall with A-60 class equivalence
- The wall/ cabin element was further investigated in two possible designs:
  - Using steel and insulation
  - Using novel composite materials

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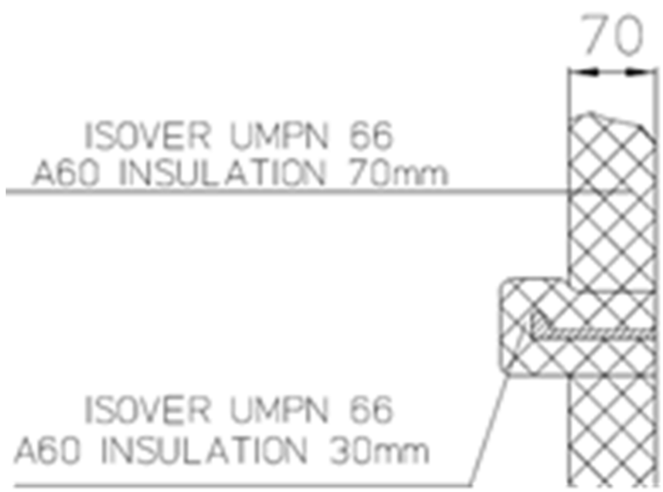
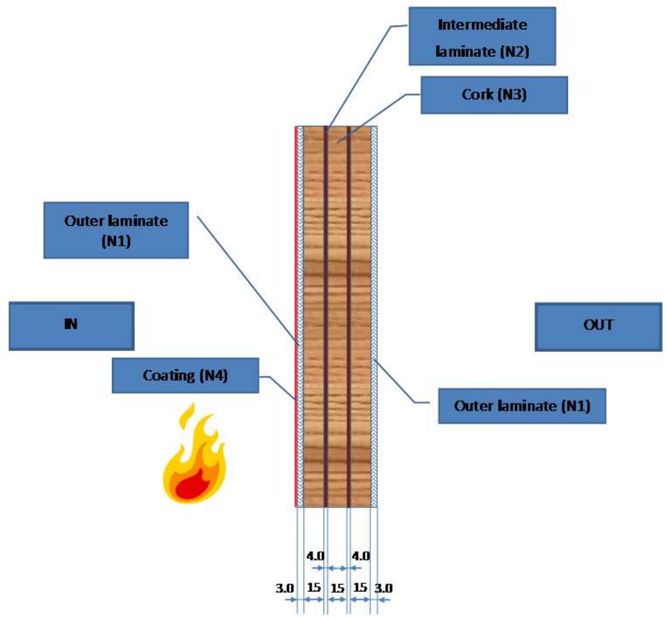
Case studies: reference and novel design

- Comparative thermo-mechanical analysis was carried out for a typical bulkhead of A-60 Class:
  - Following test requirements of FTP Code
  - Traditional steel (1) and novel composite (2) solutions





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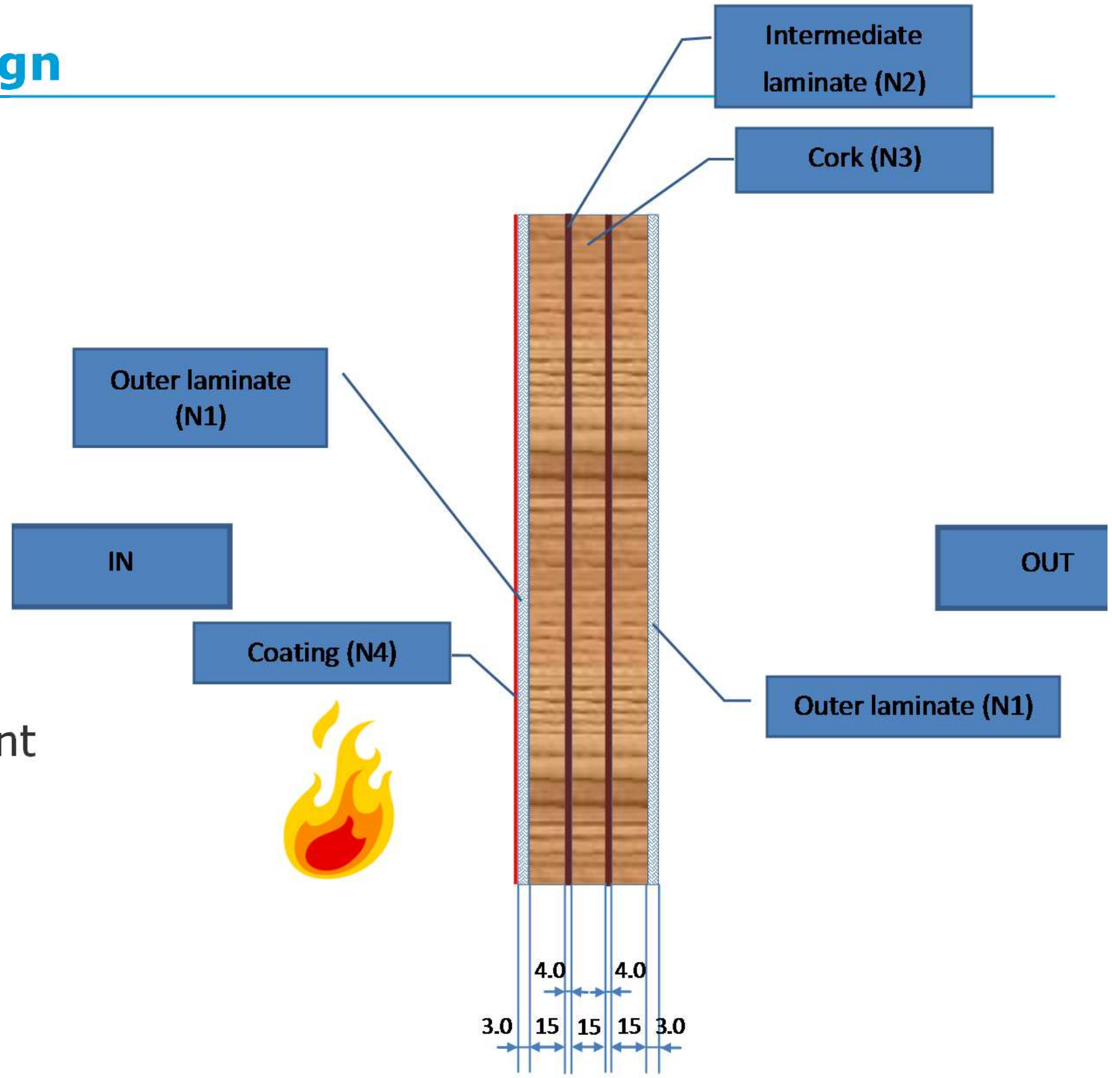
Case study$_1$: composite design

- Novel composite sandwich
  - furan resin matrix and glass fibres
  - cork core
  - Fire exposed laminate layer protected by intumescent coating



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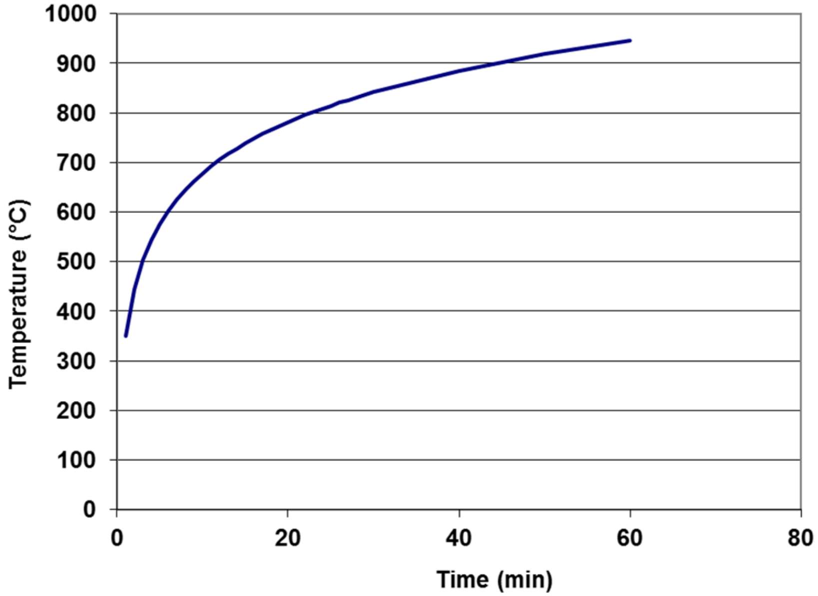
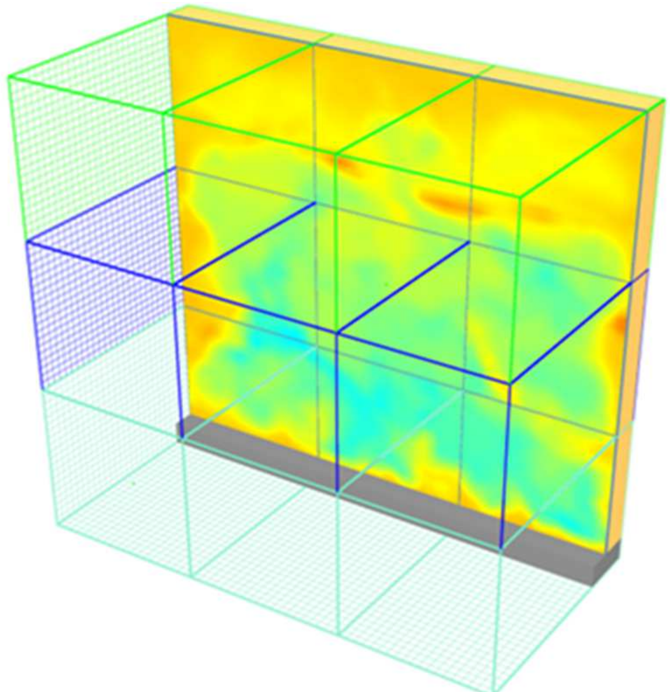
Case study$_2$: Fire Simulation

- Fire simulation using Fire Dynamics Simulator (FDS)
- Furnace walls follow ISO 834 time-temperature curve
- The FDS model considers eight air inlets and eight air outlets of 100 mm × 100 mm, volume flow is 50 l/s
- Furnace size is 2950 mm × 1500 mm ×3000 mm with 50 mm mesh resolution





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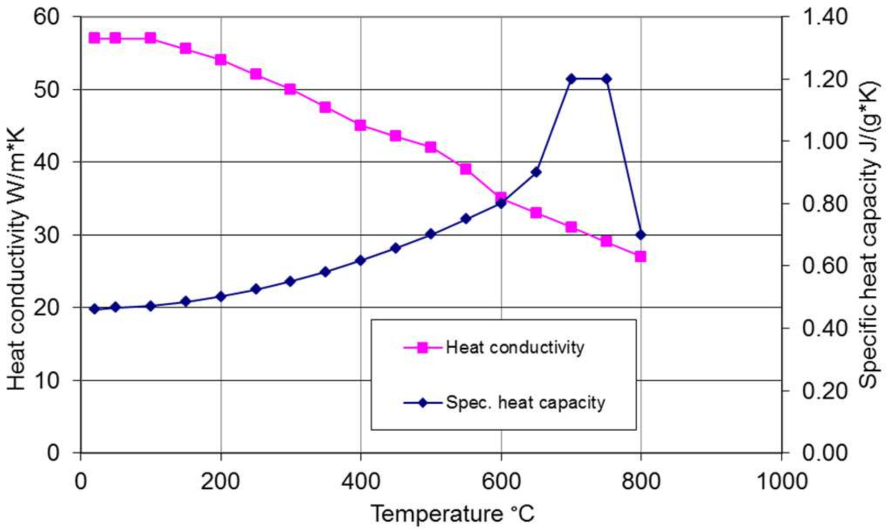
Case study$_3$: material properties modelling

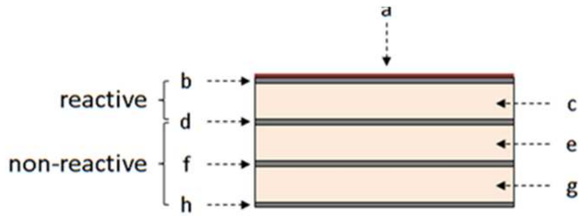
Steel

- Temperature dependent properties
  - Thermal conductivity
  - Specific heat capacity
  - Thermal expansion
  - Yield strength



Composite

- Reactive material for first two layers



  - Intumescent coating is modelled as a 50 mm thick, non-reactive, layer of material with a Furan laminate: three step decomposition reaction
- 2nd & 3rd cork layer: temperature dependent thermal conductivity and specific heat capacity
- All other layers: constant thermal conductivity and specific heat capacity

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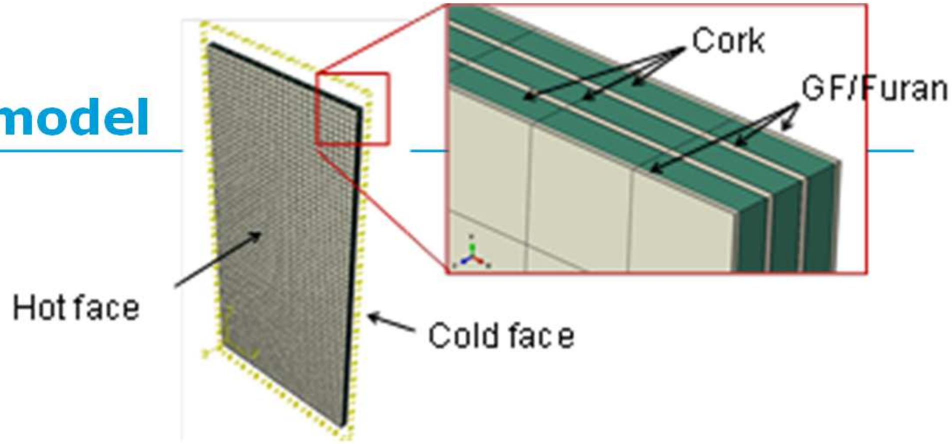
Case study$_4$: composite material model



- Composite
  - For mechanical FEA
    - Linear elastic behaviour assumed
    - Temperature dependent properties for
      - Cork
        - Modulus decreases from 15 MPa (RT) to 5 MPa (150°C)
      - Composite
        - Mori-Tanaka homogenisation scheme has been used to estimate composite unidirectional (UD) ply properties

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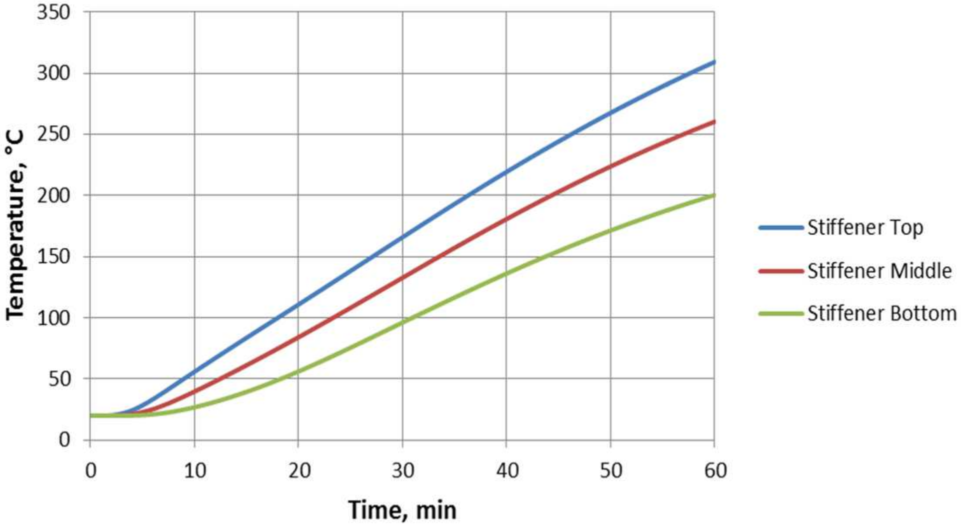
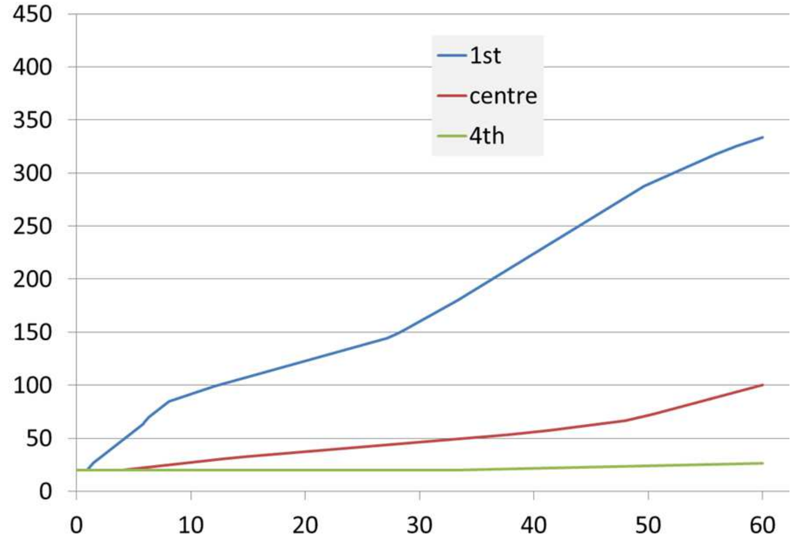
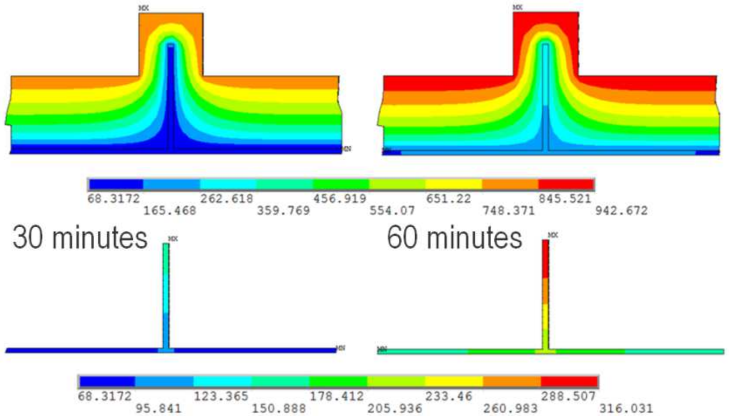
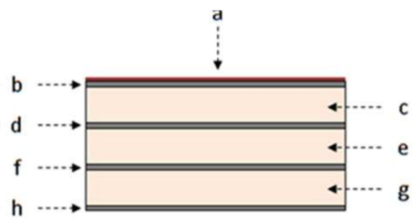
Results$_1$: thermal calculation

- Temperature: reference vs. novel design









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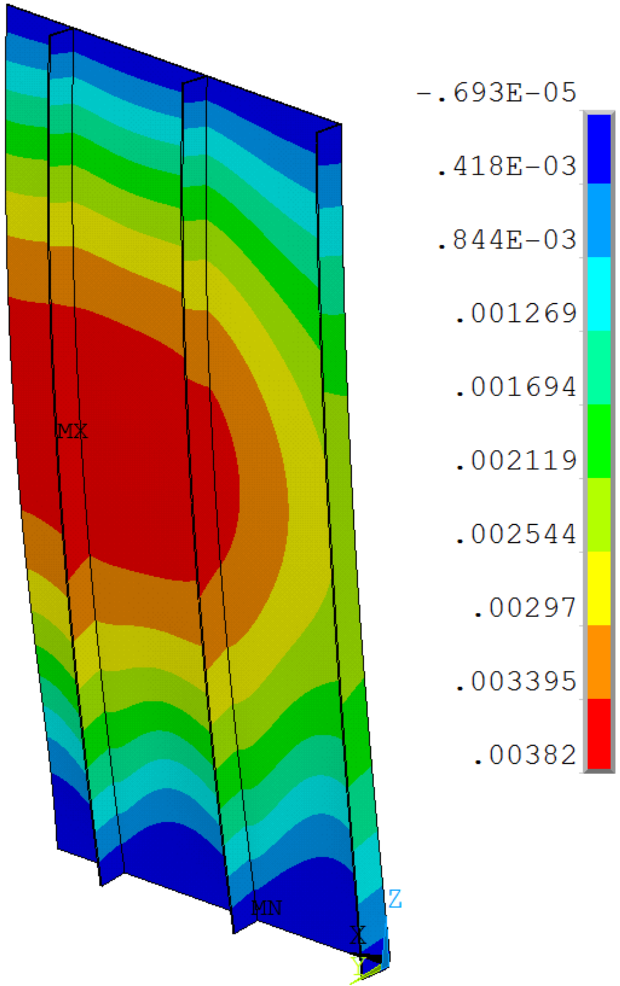
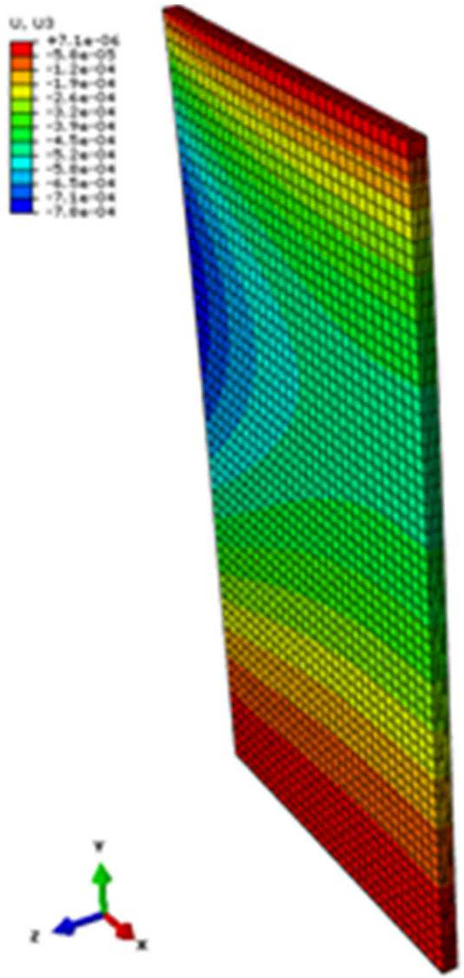
Results$_2$: horizontal deflection for ~15 min (magnitude x 20)





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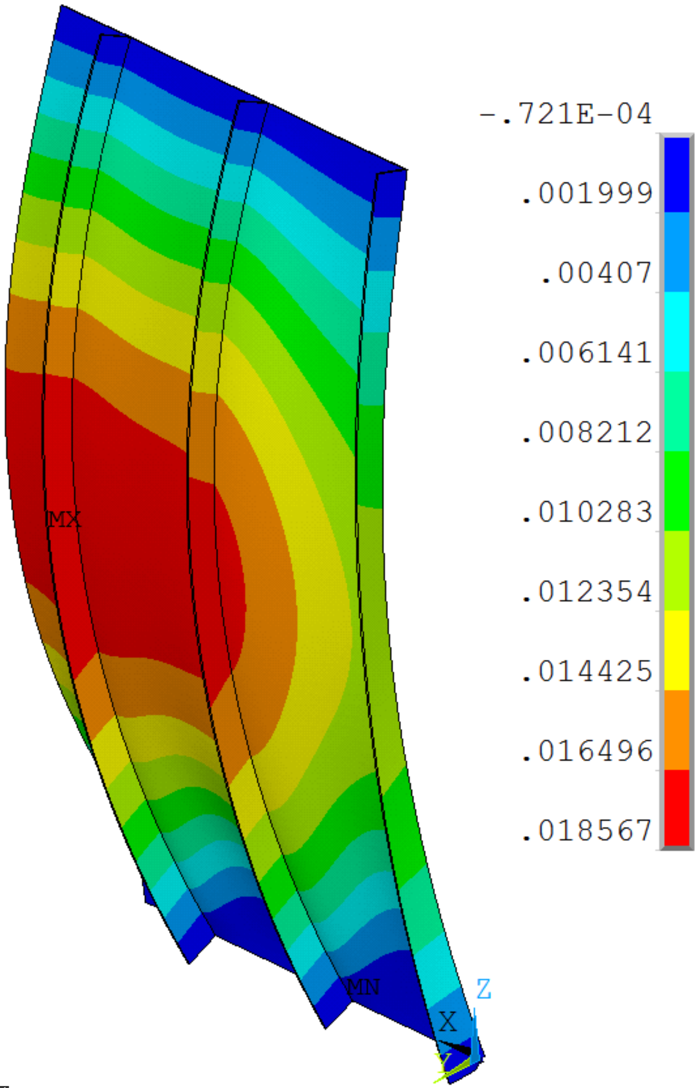
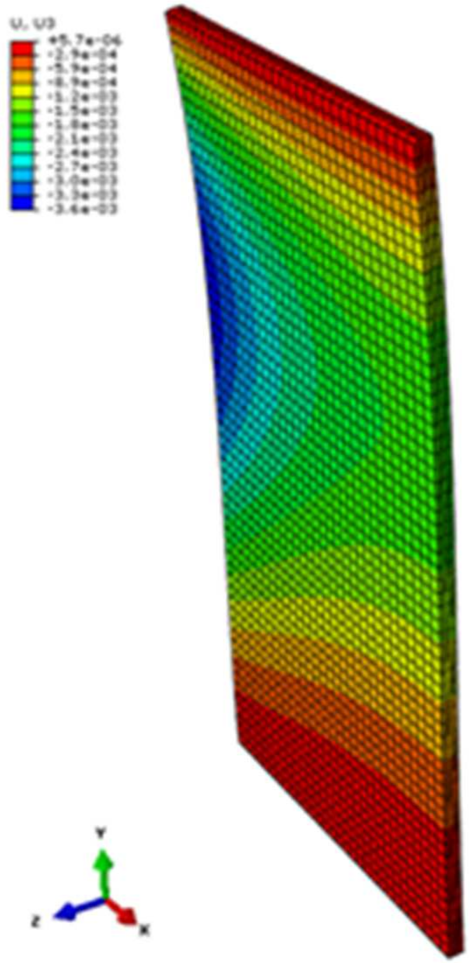
Results$_3$: horizontal deflection for ~60 min (magnitude x 20)





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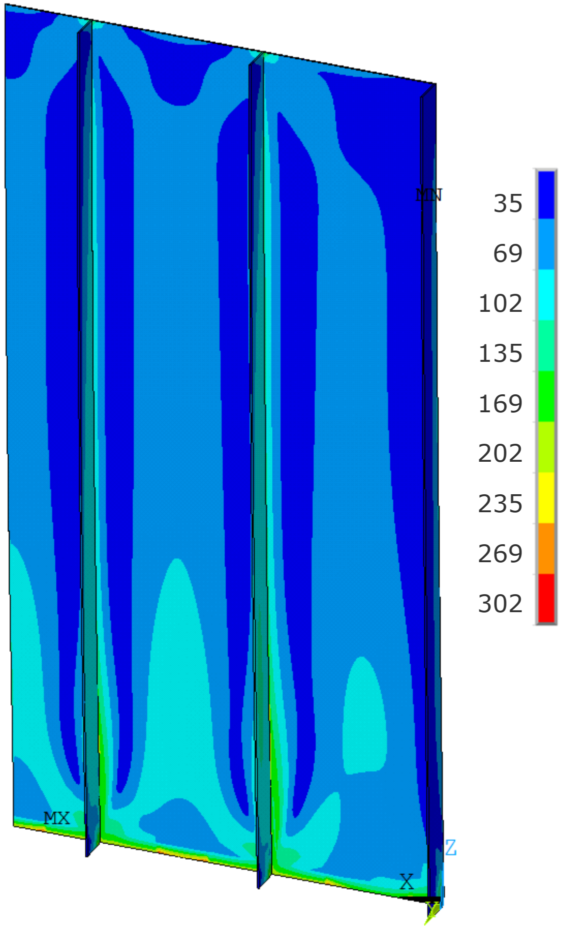
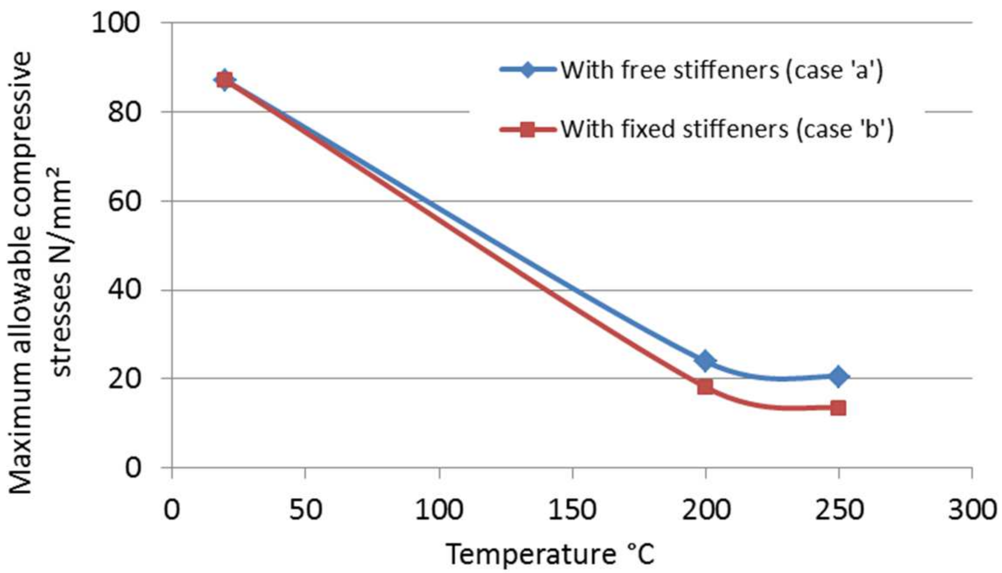
Results$_4$: mechanical results for steel design after 60 min

von Mises stresses (N/mm²)



load-bearing capacity (based on DIN-18800-3) using deflections and stresses from ANSYS calculation



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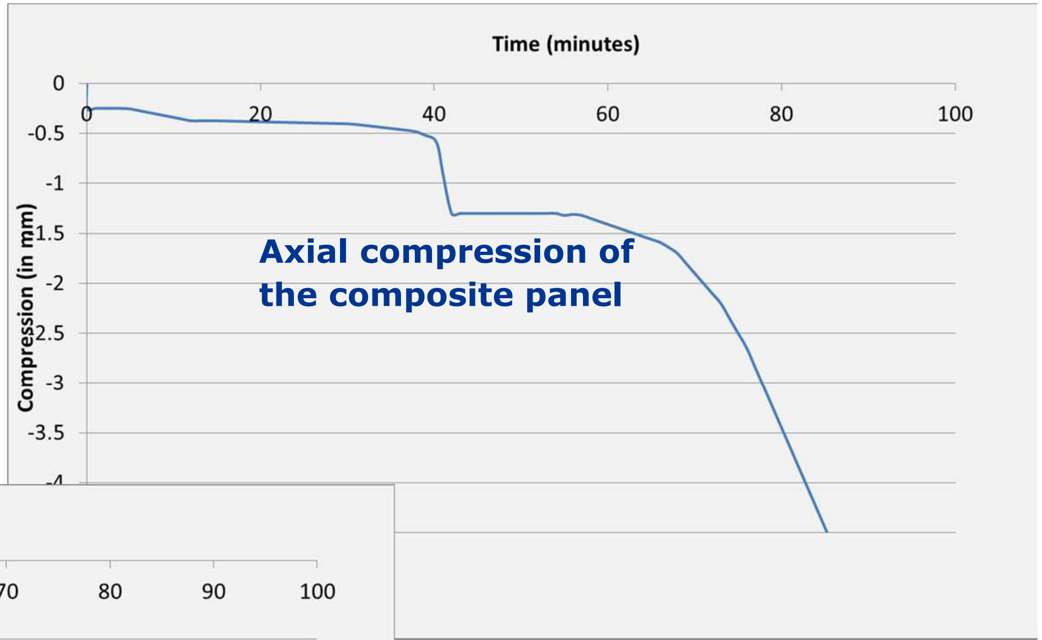
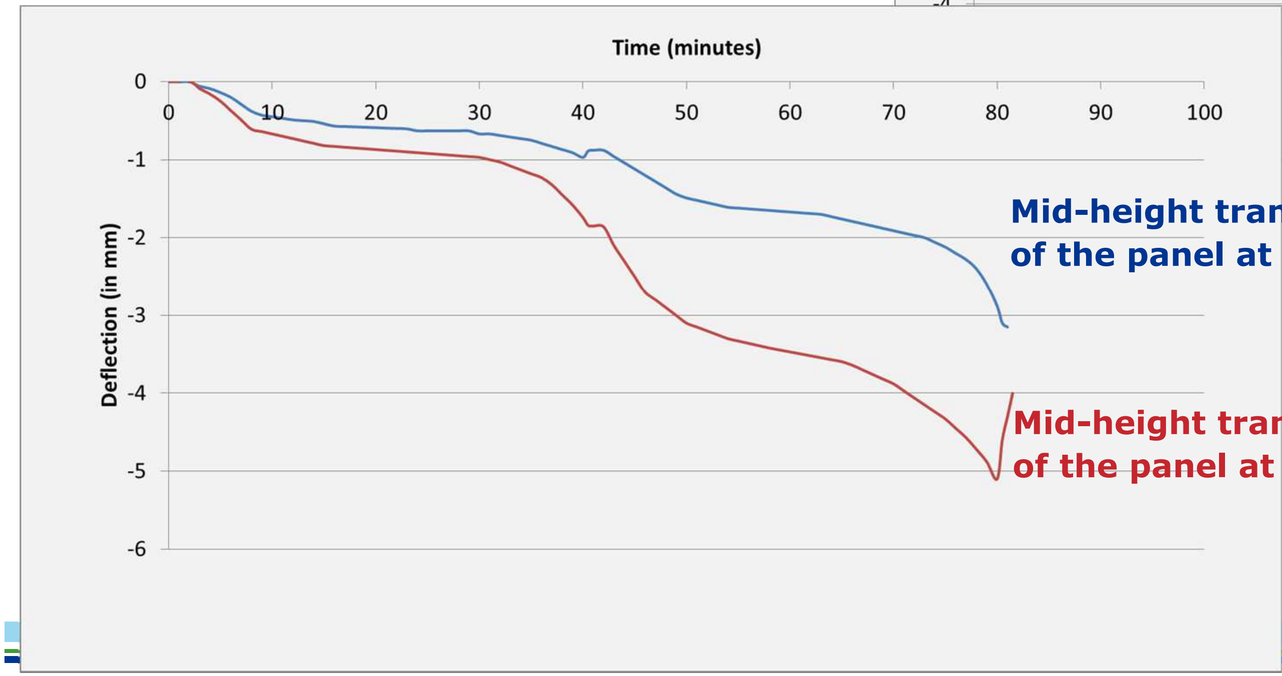
Results$_5$: mechanical results for composite design after 60 min





Mid-height transverse deflection of the panel at the centre

Mid-height transverse deflection of the panel at one edge

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Comparison based on numerical results after 60 min fire exposure

Criterion	Insulated steel bulkhead	Composite bulkhead
Average temperature rise on unexposed side (requirement ≤ 140°C)	137°C	≤ 5°
Maximum temperature rise on unexposed side (requirement ≤ 180°C)	183°C (fulfilled considering numerical uncertainty)	≤ 5°C
Load bearing capacity	25 N/mm²	2.1 N/mm²
Relative loss of load bearing capacity	71%	~95%
Structural integrity (keep fire in compartment of origin)	Fulfilled: The bulkhead keeps its structural integrity but experiences significant load-bearing capacity reduction. It still has structural reserves (29% of the initial state or 25 N/mm² in terms of stresses)	*Fulfilled: The bulkhead keeps its structural integrity. (*) However, the load-bearing limit is reached and no more structural reserves are available

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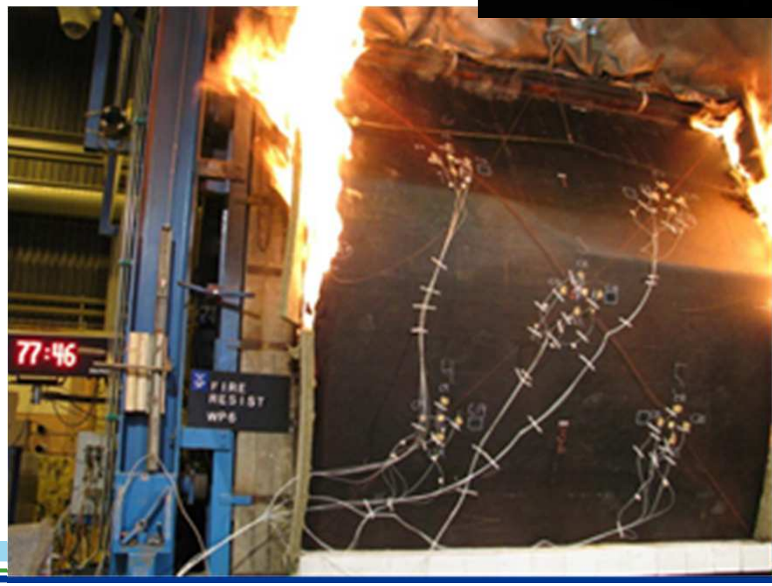
Fire test (performed at SP)

- A fire test was performed in order to
  - Verify the simulation process for composite material
  - Demonstrate the capabilities of the materials developed in Fire-Resist

Inner surface 40 minutes



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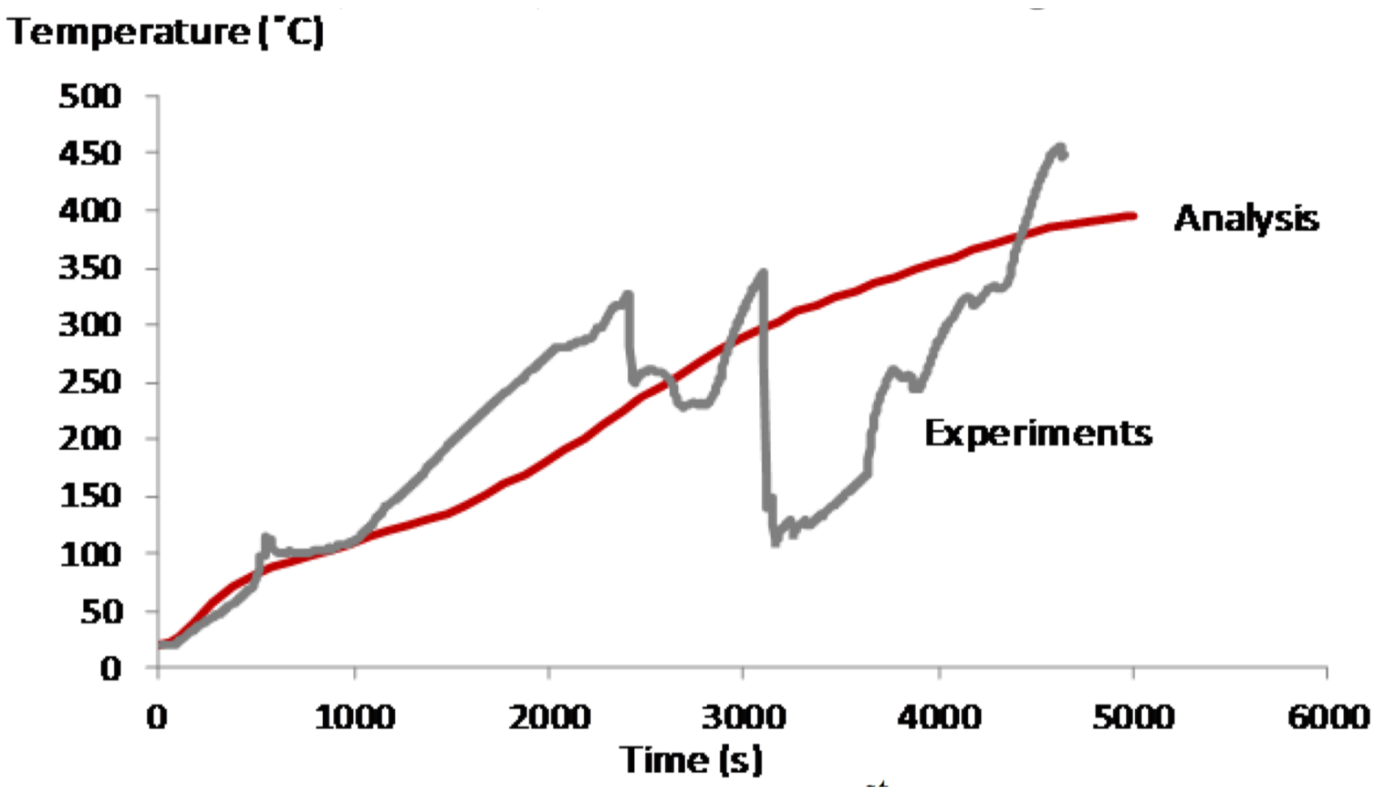
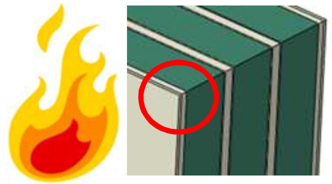
Comparison between 1st laminate temperatures measured during the test and simulated with the FEA (test data: SP)

- Comparison between 1st laminate temperatures measured during the test and simulated with the FEA





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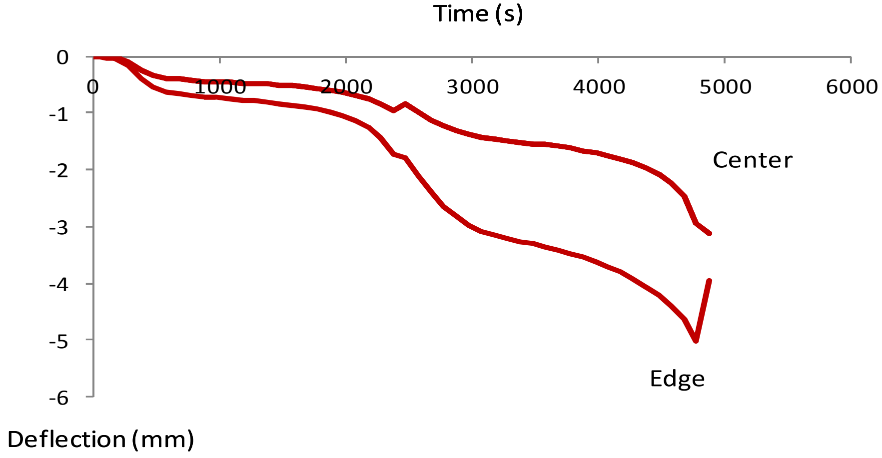
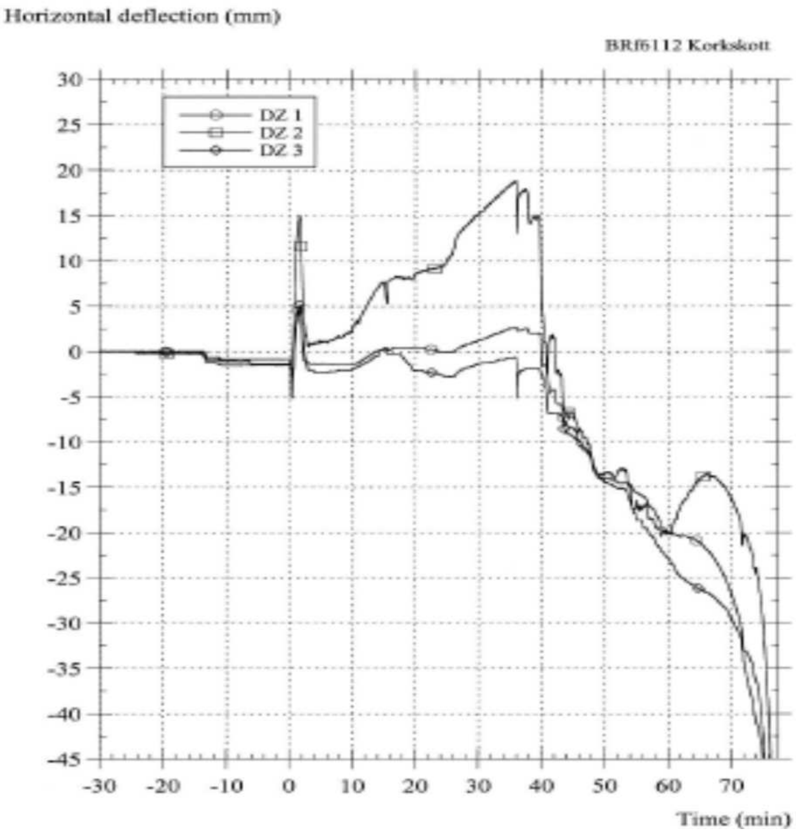
Comparison: measured and simulated horizontal deflection of the composite bulkhead (test data source: SP)

- The trend of the curves is very well predicted
- A time of a first instability predicted at 40 min
- Final collapse predicted starting at 65 min





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Summary & Conclusion

- Usage of composite materials in shipping industries limited
- Possibility to overcome limitations: IMO Alternative Design
- Thermo-mechanical analysis can help
  - To analyse the behaviour of structural elements during and after a fire
  - Optimise the design in order to
    - Meet the functional objectives required by regulations
    - Minimise experiments
  - To comparatively analyse novel and reference materials with respect to their fire behaviour
- In Fire-Resist a concept for numerical fire simulation and subsequent thermo-mechanical analysis was developed
- This concept is based on FDS fire simulation and allows thermo-mechanical analysis using ANSYS or ABAQUS

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Summary & Conclusion

- This concept was exemplarily applied to a bulkhead made of two different materials:
  - Traditional steel insulated
  - Novel composite consisting of cork and furan laminate protected by intumescent coating
- The results demonstrate the capabilities of this concept providing an excellent possibility for detailed analysis of structural fire behaviour

Thank you for your kind attention

Pavel Golyshev
pavel.golyshev@dnvgl.com

www.dnvgl.com

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