FIBRESHIP
INTEGRAL COMPOSITE SHIP

ECCOMAS Thematic Conference
VIII International Conference on Computational Methods in Marine Engineering
ECCOMAS iacm
MARINE 2019
Göteborg, Sweden, 13-15 May 2019
IACM Special Interest Conference

Thermo-mechanical analysis of laminated composites exposed to fire

Application to the analysis of ship structures

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May 12th, 2019

OVERVIEW

Solution:

Fire simulation & collapse assessment tool

Objectives:

Development of a unique GUI with the following features:

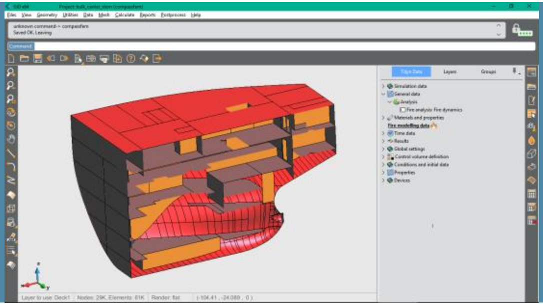
- ❑ Structural **Non-Linear Constitutive** Laminate **Composite** assessment tool.
- ❑ **Heat Transfer** + **Pyrolisis** assesment tool.
- ❑ **Fire Dynamics** tools.
- ❑ **Characterisation** of the **materials** propierties.

Components:

Tools:

- ❑ FDS
- ❑ GiD
- ❑ Tdyn-Ramseries

Fire/smoke propagation & collapse assessment tool



COUPLING ANALYSIS FOR COLLAPSE ASSESSMENT

Fire specification, ship compartments configuration, wall thermal properties...

Fire dynamics analysis (FDS)

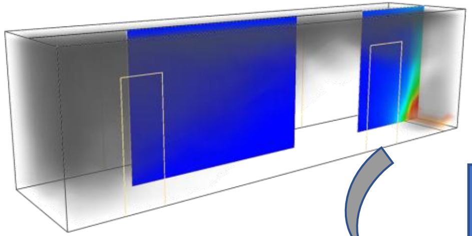
Temperature time evolution curves

Beams and shells thermal analysis (RamSeries)

Through-thickness temperature distribution in beams and shells

Beams and shells structural analysis (RamSeries)

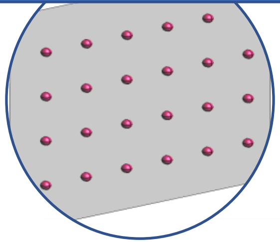
Collapse risk assessment



Fire dynamics analysis

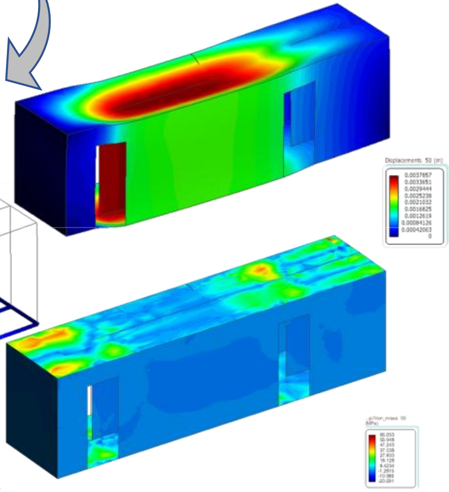
Temperature distribution due to is obtained at the surface of decks, bulkheads and other structural elements due to their exposure to fire.

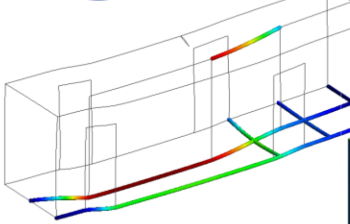
Transfer temperature information from control points to the structural model



Thermomechanical analysis

Displacements, strains and stresses over structural components using a thermomechanical constitutive model including pyrolysis

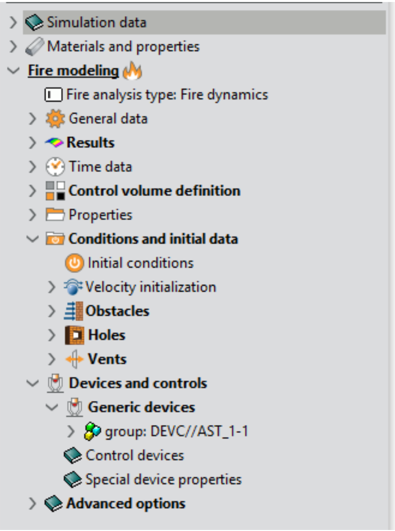


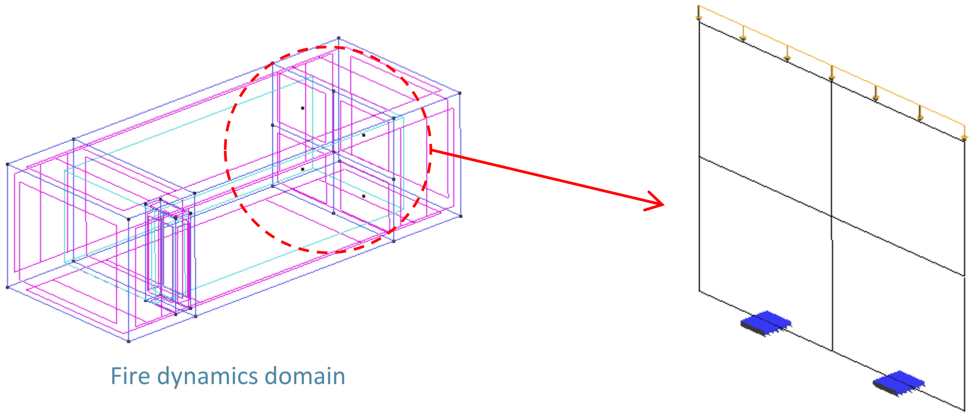


GUI FOR THE DEFINITION OF COLLAPSE ASSESSMENT MODELS

A complete GUI for the definition of FDS models was integrated into the RamSeries FEM simulation suite.

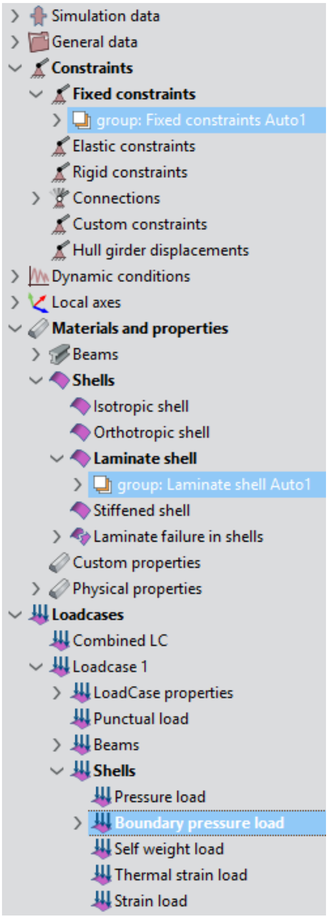
- A unique geometrical model can be used for the definition of both, FDS fire dynamics and RamSeries structural models.
- A common materials database is shared by the two solvers.
- It allows an easy definition of the communication interface and the data to be transferred between the two solvers.





Fire dynamics domain

Structural thermo-mechanical domain



MATERIALS DATABASE: Definition of composite materials

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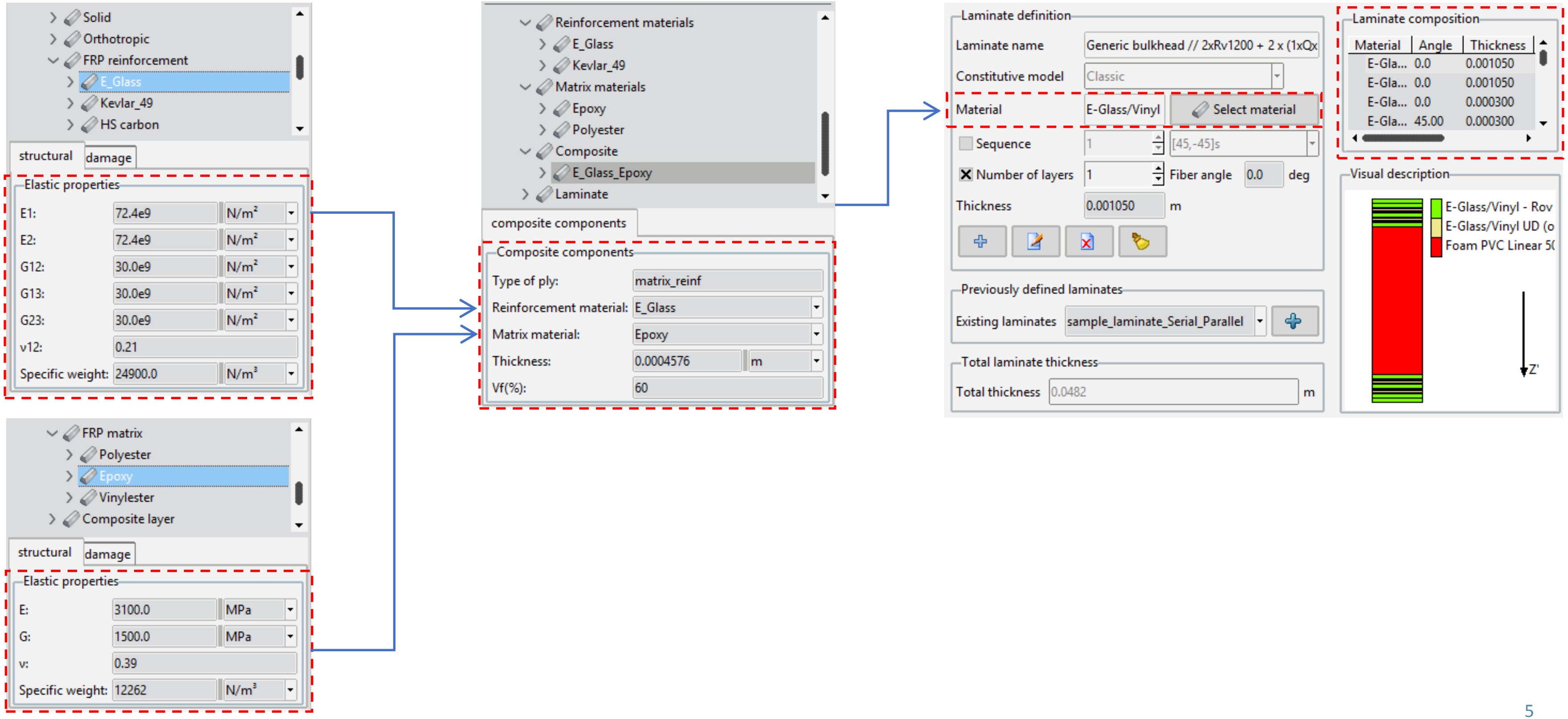
Definition of individual components

Definition of composite layers

Definition of laminate materials



THERMOMECHANICAL: Composite Constitutive Model

Classic Solution

(Rule of Mixtures)

- **FEBLE** link between micro-macro scale.
- Properties referred to the **EQUIVALENT** composite.
- **LOW** computational cost.
- **ORTHOTROPIC** materials.
- **LOWER** transversal estimation and **DIFFICULT** prediction in Non-Linear range.

Precise Solution

(Serial-Parallel ROM)

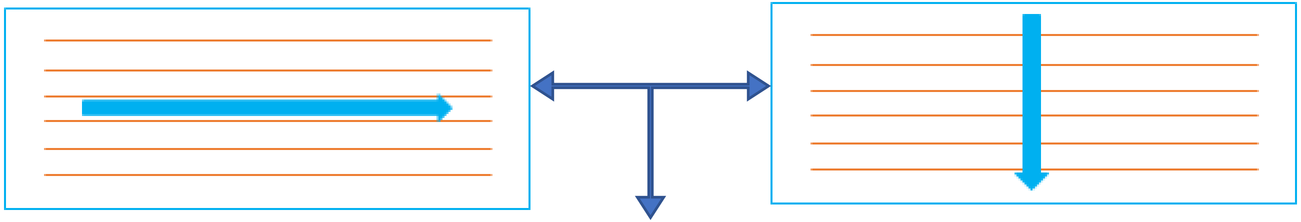
- **STRONGER** link between micro-macro scale.
- Properties referred to **EACH** component.
- **HIGHER** computatinal cost.
- **ISOTROPIC** material.
- **GOOD** tranversal estimation and **ACCURATE** prediction in Non-Linear range.

Serial-Parallel Rule of Mixtures (Rastellini *et al., 2008*[1])

- Orthotropy achived by CLOSURE EQUATIONS.
- Separate internal variables.

Parallel direction $\begin{cases} \boldsymbol{\varepsilon}_p = \boldsymbol{\varepsilon}_p^f = \boldsymbol{\varepsilon}_p^m \\ \boldsymbol{\sigma}_p = k^f \boldsymbol{\sigma}_p^f + k^m \boldsymbol{\sigma}_p^m \end{cases}$

Serial direction $\begin{cases} \boldsymbol{\varepsilon}_s = k^f \boldsymbol{\varepsilon}_s^f + k^m \boldsymbol{\varepsilon}_s^m \\ \boldsymbol{\sigma}_s = \boldsymbol{\sigma}_s^f = \boldsymbol{\sigma}_s^m \end{cases}$

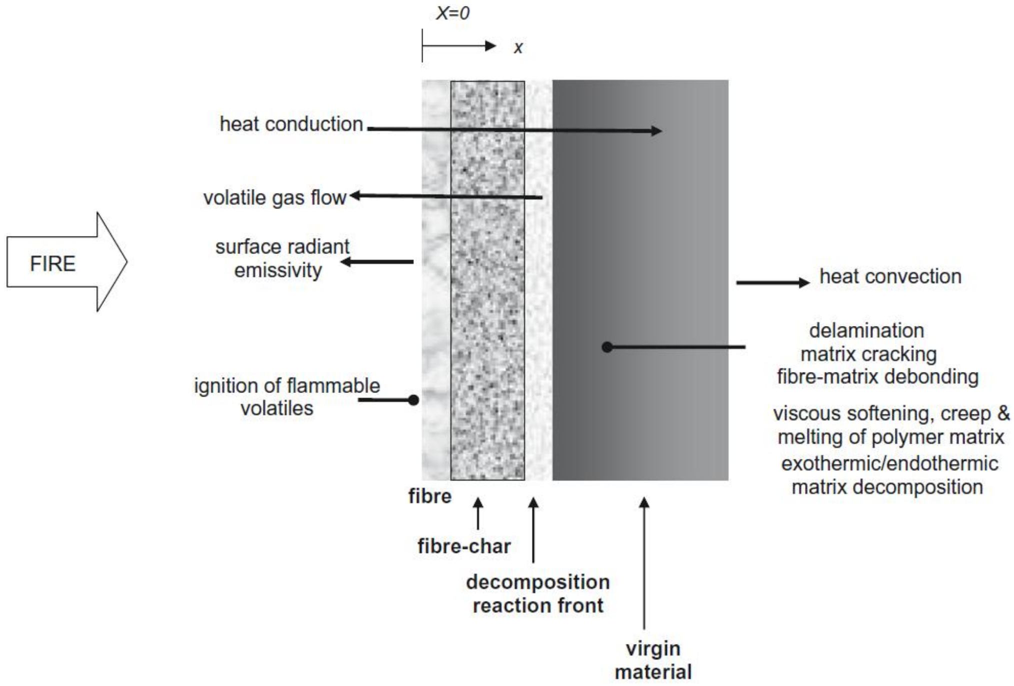


$$\left[\Delta\boldsymbol{\varepsilon}_s^m\right]_0 = \mathbf{A}:\left[\mathbf{C}_{ss}^f:\Delta\boldsymbol{\varepsilon}_s + k_f\left(\mathbf{C}_{sp}^f - \mathbf{C}_{sp}^m\right):\Delta\boldsymbol{\varepsilon}_p + k_f\Delta\boldsymbol{\sigma}_T^m - k_f\Delta\boldsymbol{\sigma}_T^f\right]$$

Isotropic Damage Model (Simu&Ju,1987[2])

[1] Rastellini, Fernando & Oller, Sergio & Salomon, Omar & Oñate, Eugenio. (2008). Composite materials non-linear modelling for long fibre-reinforced laminates. Continuum basis, computational aspects and validations. Computers & Structures. 86. 879–896. 10.1016/j.compstruc.2007.04.009.

[2] Simo, J.C., [1987a], "On a Fully Three-Dimensional Finite-Strain Viscoelastic Damage Model: Formulation and Computational Aspects," Computer Methods in Applied Mechanics and Engineering 60, 153–173.



The thermal model analyses the energy transfer processes of **heat conduction**, **pyrolysis of the polymer matrix**, and **diffusion of decomposition gases**. The resultant model is expressed as a one-dimensional non-linear equation that incorporates these processes

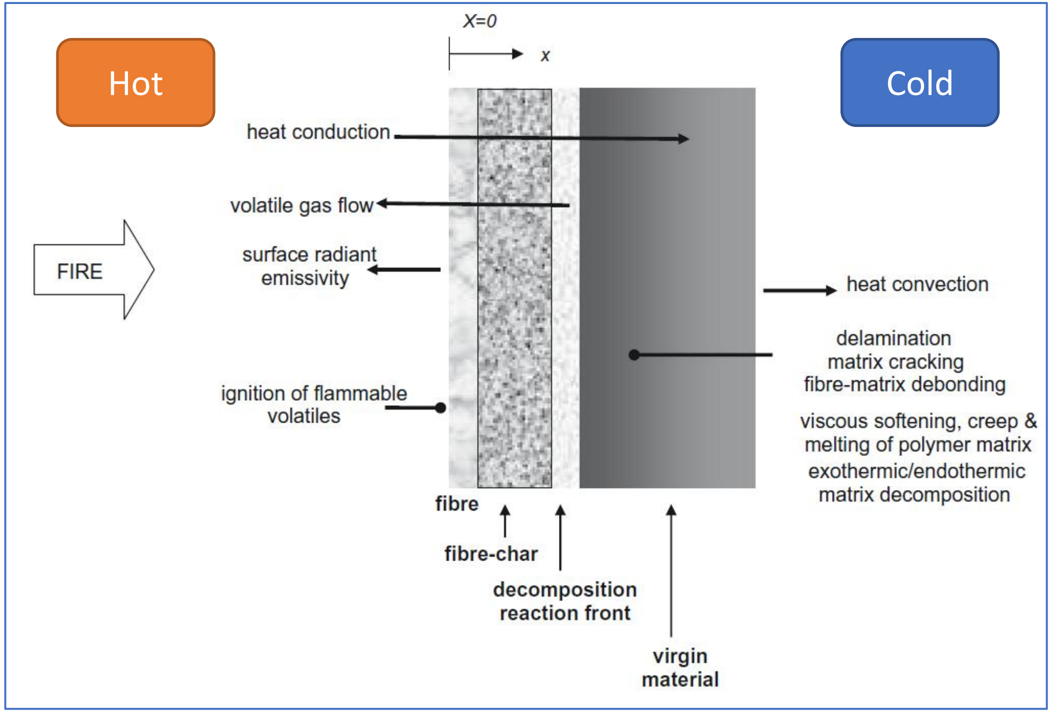
Henderson et al., 1985[3]

$$\rho C_p \frac{\partial T}{\partial t} = \frac{\partial}{\partial x}\left(k \frac{\partial T}{\partial x}\right) - \frac{\partial\left(w_g h_g\right)}{\partial x} + \dot{m}_{s\to g}\left(Q_p + h_c\right)$$

$$\rho = F\rho_0 + (1-F)\rho_f$$

[3]Henderson JB, Wiebelt JA, Tant MR. (1985) A model for the thermal response of polymer composite materials with experimental verification. J Compos Mate; 19:579–95.

HEAT TRANSFER AND PYROLYSIS – 1D



Evolution Law

$$\frac{dF}{dt} = -A\left[\frac{\rho-\rho_f}{\rho_0-\rho_f}\right]^N e^{-\frac{E}{RT_k}} = -AF^N e^{-\frac{E}{RT_k}}$$

Initial Conditions

$$\rho(t) = \rho_0 \qquad T(t) = T_0$$

Boundary Conditions

Hot face:

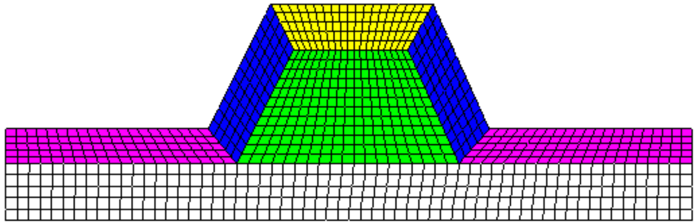
$$q(t,0) = -k\frac{\partial T}{\partial x} = \sigma\varepsilon_m\left(T_{adk}^4 - T_k^4\right) + h_{conv}\left(T_{ad} - T\right)$$

Cold face:

$$q(t,l) = -k\frac{\partial T}{\partial x} = \sigma\varepsilon_m\left(T_k^4 - T_{\infty k}^4\right) + h_{conv}\left(T - T_\infty\right)$$

[3]Henderson JB, Wiebelt JA, Tant MR. (1985) A model for the thermal response of polymer composite materials with experimental verification. J Compos Mate; 19:579–95.

HEAT TRANSFER AND PYROLYSIS – 2D



- 1D theory is used for **PLATES** and **BULKHEADS** (shells).
- 2D theory is used for **BEAMS** as shell reinforcement elements.
- Provides a **high accuracy** solution with **low computational cost**.

$$\rho C_p \frac{\partial T}{\partial t} = \nabla \cdot (k_T \nabla T) - \rho_g C_{pg} \mathbf{v}_g \cdot \nabla T + \dot{m}_{s\to g}\left(Q_p + h_c - h_g\right)$$

$$\frac{\partial(\phi_g \rho_g)}{\partial t} = -\nabla \cdot (\rho_g \mathbf{v}_g) + \dot{m}_{s\to g}$$

$$\frac{\partial \rho}{\partial t} = -\underbrace{\nabla \cdot (\mathbf{w}_s)}_{=0} - \dot{m}_{s\to g}$$

Extension of 1D HTP+Pyrolysis to 2D for Non-Linear Constitutive Beams

- Addition of convective term (gas escapement)

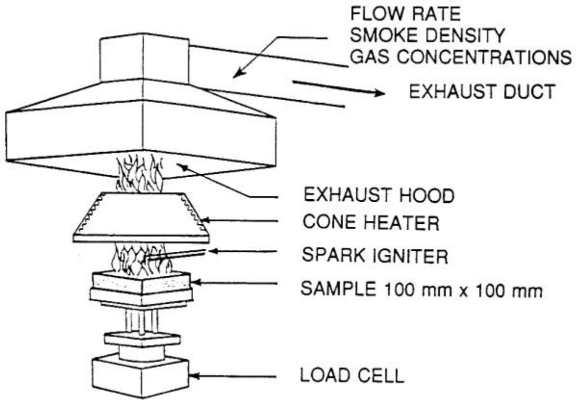
$$\rho_g C_{pg} \mathbf{v}_g$$

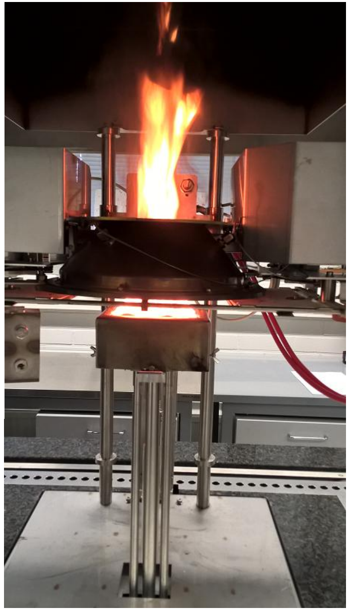
- Estimation of the gas velocity by the pressure inside the cross section

$$\mathbf{v}_g = -\frac{k_g}{\mu_g} \nabla p_g$$

- Coupling between HTP+Pyrolysis and Darcy physics (temperature and pressure) to estimate the fluxes.
  - Improvement of the hot/cold end B.C.
  - More natural solution.

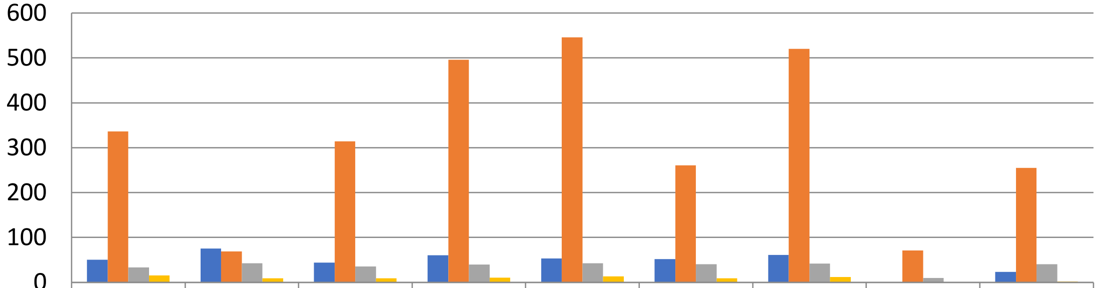
Within the scope of FiberShip there is a budget dedicated to the characterization of composite materials.





Cone calorimeter test ISO 5660-1

THERMAL AND PYROLYSIS CHARACTERISATION OF COMPOSITE MATERIALS



	LEO system without topcoat	LEO system with topcoat	Crestapol 1210	Prime 27	SR1125 without topcoat	SR1125 with SGi 128 topcoat	Super Sap CLR	Cellobond J2027X	Elium
tig (s)	50	75	44	60	53	52	61	0	23
HRRmax (kW/m2)	336	69	314	496	546	261	520	71	255
THR (MJ/m2)	33.5	42.3	35.4	39.4	42.5	40.7	42	9.9	40.7
TSP (m2)	15.1	8.8	9.3	10.7	13.5	9.3	12	0.4	1.8

First stage tests performed by *VTT Technical Research Centre of Finland Ltd, Finland*. Properties measured are **time of ignition**, **heat release rate per unit area**, **total heat release per unit area**, **total smoke production**.

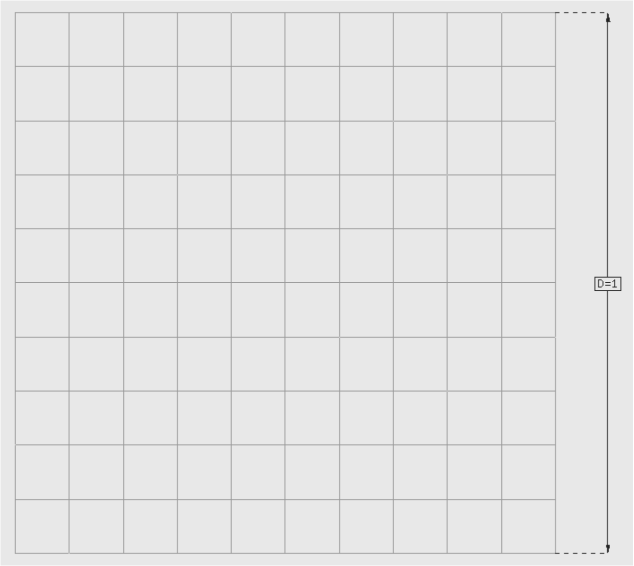
FIBRESHIP

1. Leo system with topcoat
2. SR1125 with SGi128 topcoat

- Extra property classes taken into account in the selection:
  - mechanical properties
  - manufacturing
  - Impact/safety/environment

Experimental model from Henderson et al. (1985) [3]

- Plate model of 1m x 1m .
- X, Y, Z fixed DOF.
- Structured mesh, 10 division in each direction.
- Designated material (*H41N*) is a phenolic resin with glass and talc filler.



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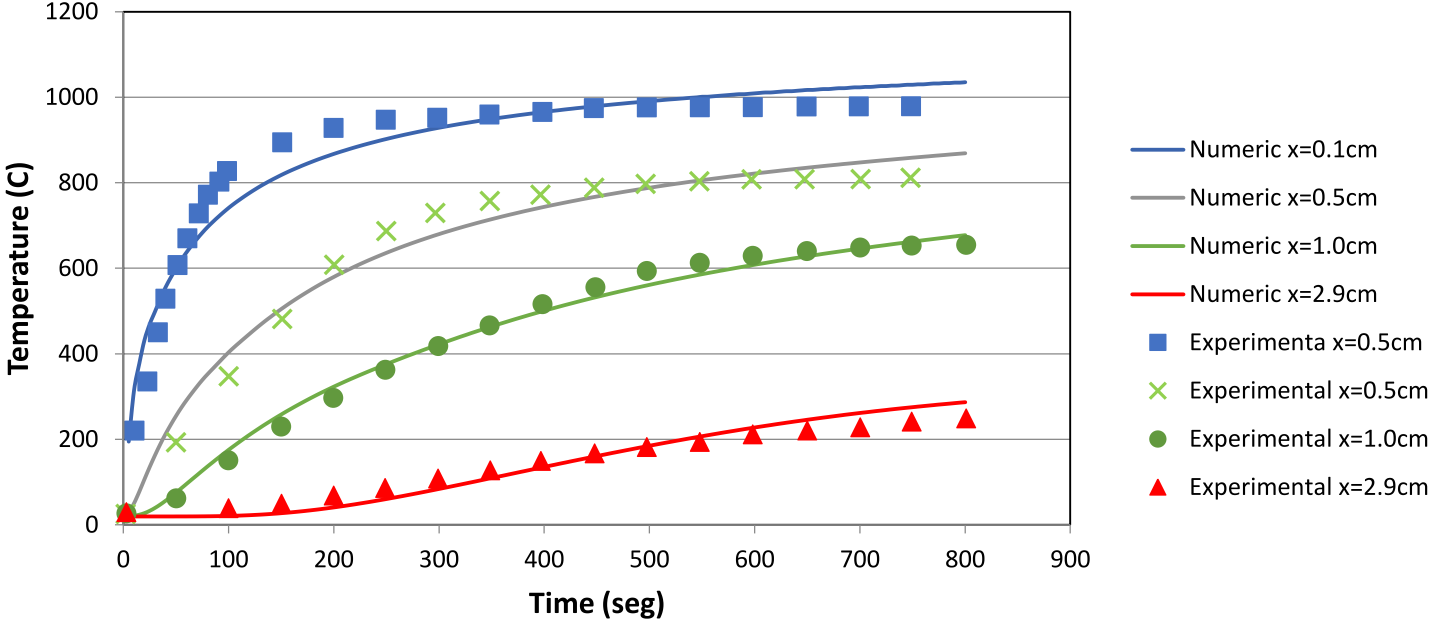
HENDERSON BENCHMARK MODEL

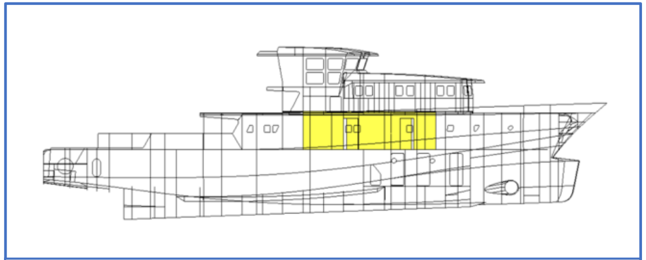


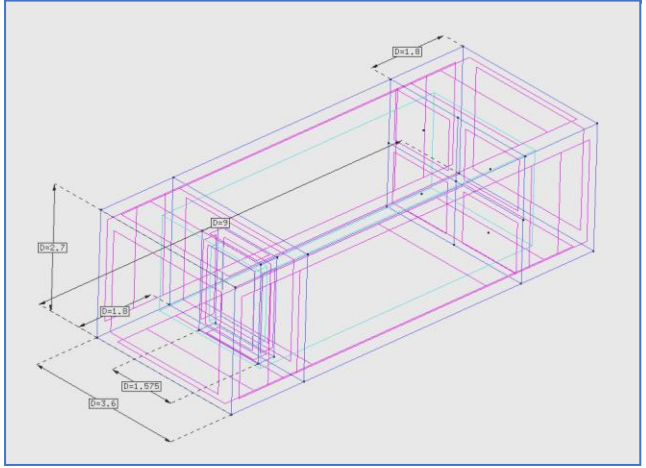
[3]Henderson JB, Wiebelt JA, Tant MR. (1985) A model for the thermal response of polymer composite materials with experimental verification. J Compos Mate; 19:579–95.

SIMULATION OF A SHIP COMPARMENT

Domain using FDS tool to obtain the temperature evolution map

- Compartment model[4].
- Supported on the floor.
- Structured mesh size of 0.1m .
- The complete floor is on fire.

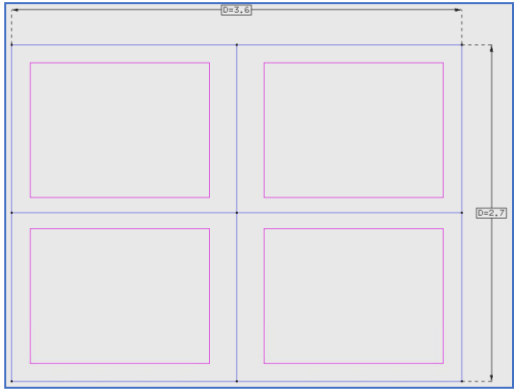


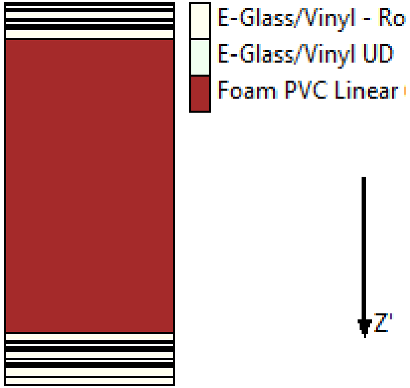


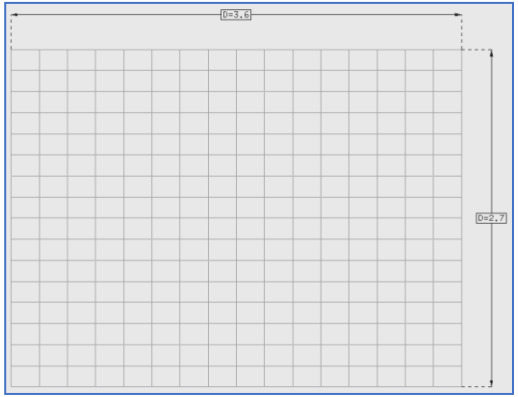
[4] Automated two-way coupled CFD fire and thermomechanical FE analyses of a self-supporting sandwich panel façade systemde Boer, J. G. G. M. (Author). 26 Jun 2018

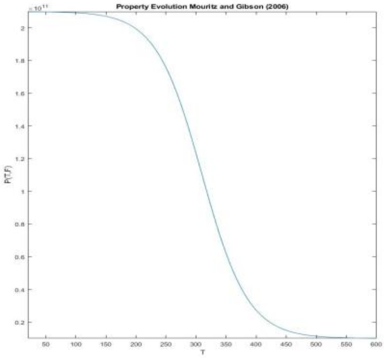
Bulkhead of the compartment domain to be analysed using the thermomechanical tool

- Plate model 3.6m x 2.7m[4]. .
- 4 points of control to retrive from FDS.
- X, Y, Z fixed DOF.
- Structured mesh: 20 x 20 divisions.
- Included gravity as body force.
- Linear Constitutive Model.









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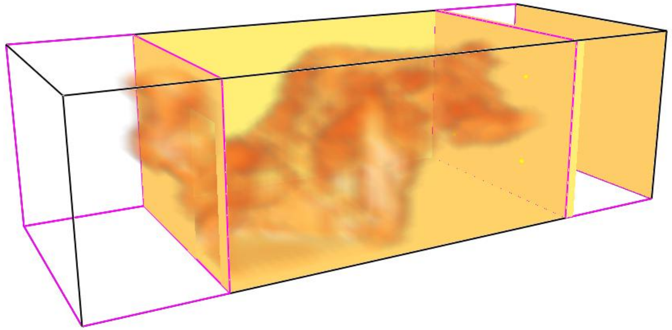
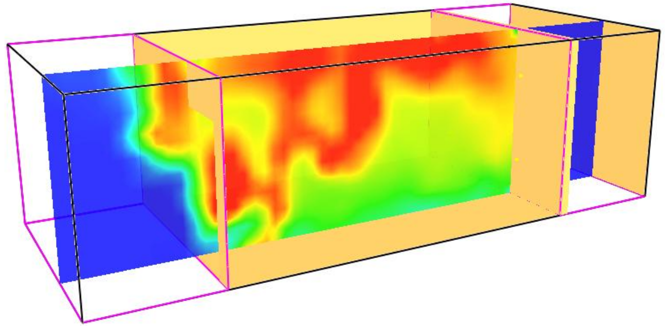
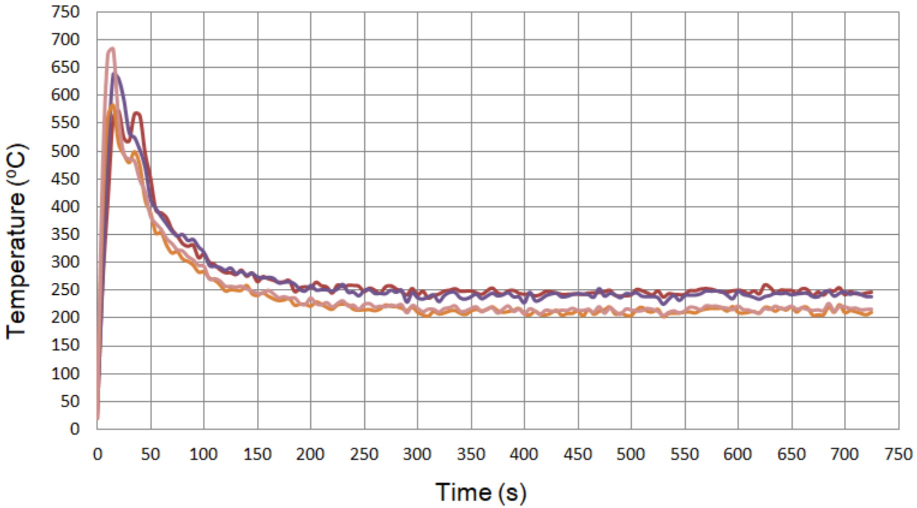


Heat release rate per unit volume (HRRPUV)
HRRPUV > 133 kW/m^3

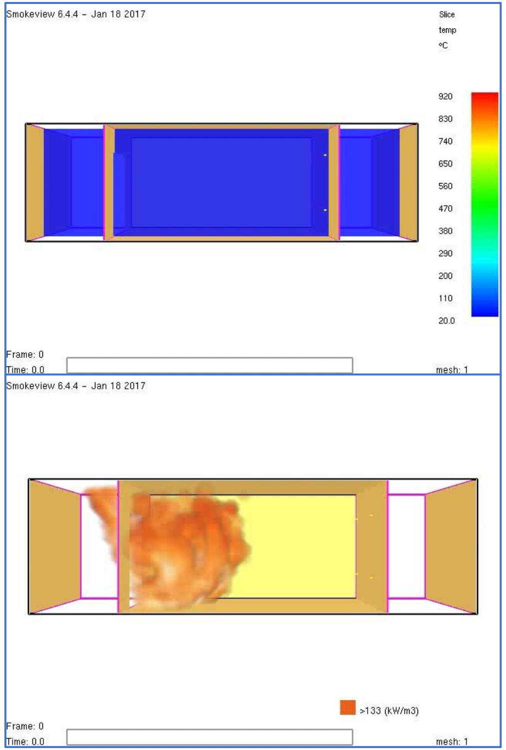


Temperature map at the middle cross-section of the room

- The adiabatic surface temperature is monitored at selected control points located at the surface of the composite panel. This information is transferred to RamSeries to be used as boundary condition for the thermo-mechanical problem.

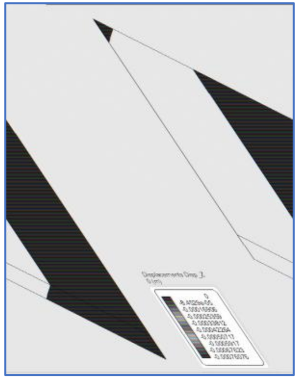


Fire Dynamic Assessment

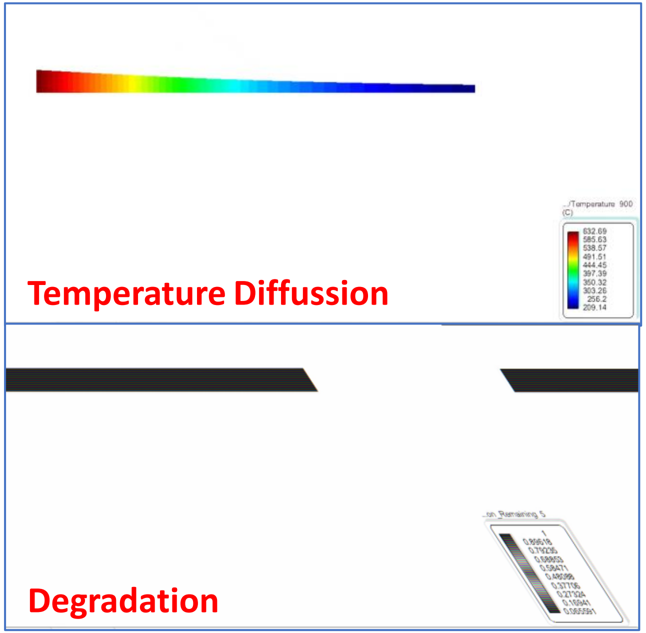


Thermo-Mechanical

Thermal-Mechanical



Thermal 1D



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CONCLUSIONS

Solution:

Fire simulation & collapse assessment tool:

- ✓ Development of an ambitious and innovative tool to assess **fire simulation & collapse for composites.**

Objectives:

Development of a unique GUI with the following features:

- ✓ Structural **Non-Linear Constitutive** Laminate **Composite** assessment tool.
- ✓ **Heat Transfer** + **Pyrolysis** assesment tool.
- ✓ **Fire Dynamics** tools.
- ✓ **Characterisation** of the **materials** propierties.

Current Development:

- ❑ Structural **Non-Linear** Laminate beam theory.
- ❑ **2D Heat Transfer + Pyrolysis** assessment tool
- ❑ **1D Heat Transfer + Pyrolysis** adaptation with Darcy problem.
- ❑ **Second stage** for the **characterisation** of the **materials** propierties.