Heat Transfers and Solid Mechanics in Microarchitectured Materials using Periodic Homogenization

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F. Viry[1], J.-D. Wheeler[1], P. Namy[1]
[1]: SIMTEC, 5 rue Felix Poulat 38000 Grenoble France

Outline

I. Background – Motivations – Objectives

II. Modelling and Numerical Model

III. Main Results

IV. Conclusions – Perspectives

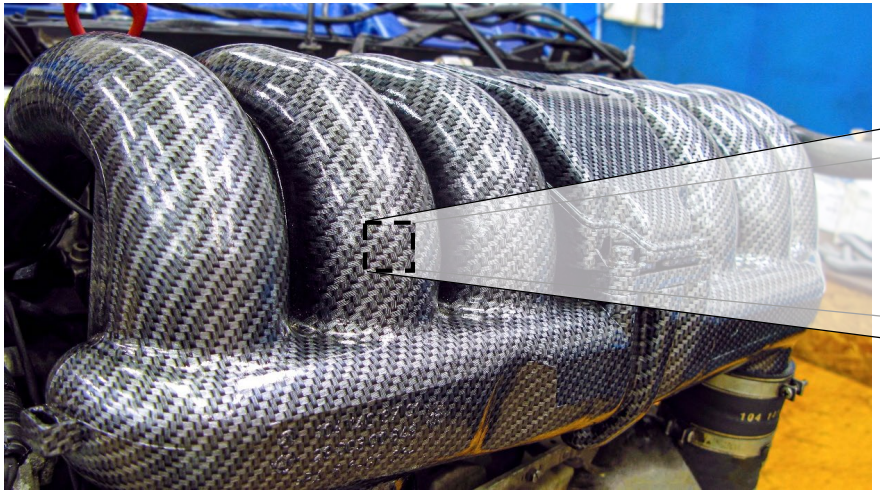
Before starting, who we are… www.simtecsolution.fr

SIMTEC : Fundamentals

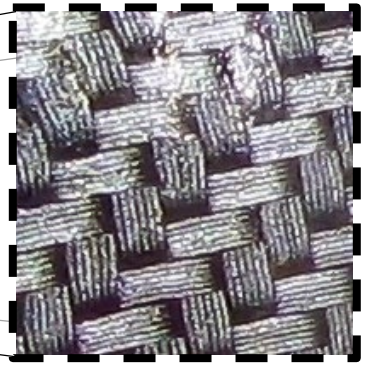
- French Numerical modelling consultancy
- Leader in France of the COMSOL Certified Consultants, key partner worldwide
- 7 members Eng.D. + Ph.D.
- Main partners:
  - big international companies
  - laboratories
- Involved in the Research projects like EU FP (SHARK, SisAl)/ PhD supervision

INNOVATION RADAR
European Commission
SHARK INDUSTRIALISING LASER FUNCTIONAL TEXTURING
SisAl Pilot

I. Background – Motivations – Objectives



Intake manifold photo from Shutterstock

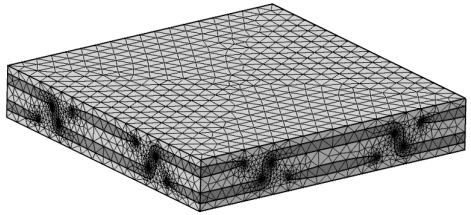


Carbon fiber pattern

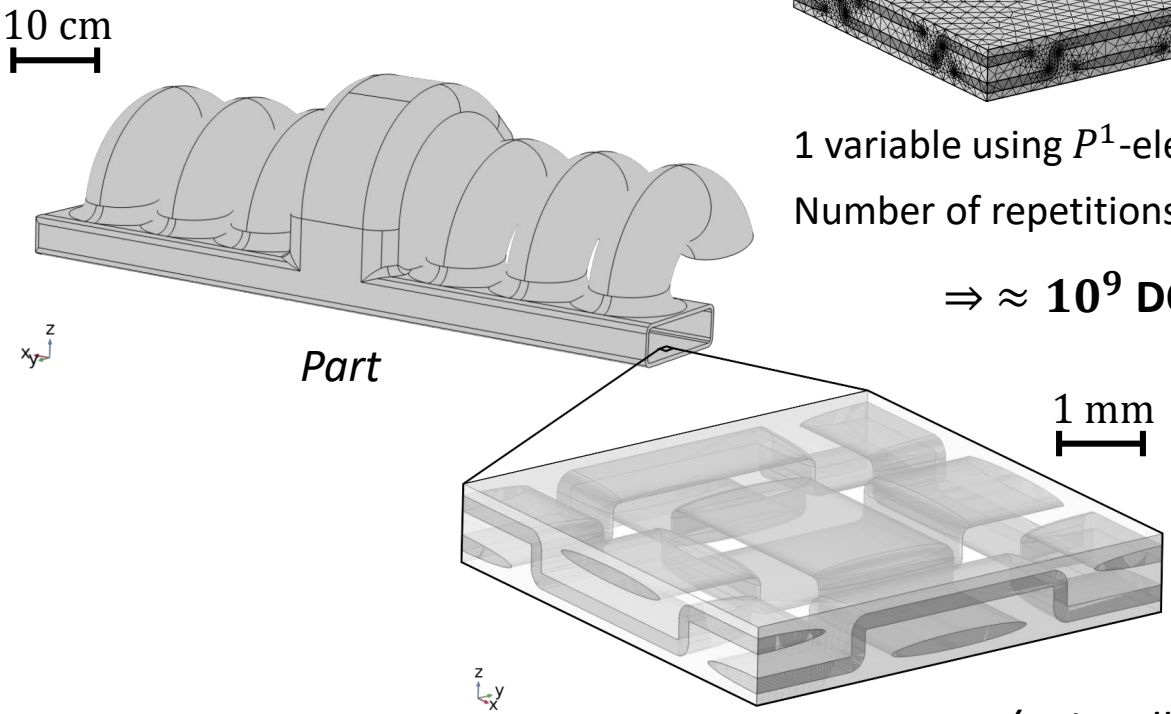
→ How to design and evaluate the performance of my part using such materials?

I. Background – Motivations – Objectives

What about direct FEA?



$\approx 100\ k$ nodes/cell



1 variable using P^1-elements $\Rightarrow \approx 100\ k$ DOF/cell

Number of repetitions of the unit cell : $\approx 10\ k$

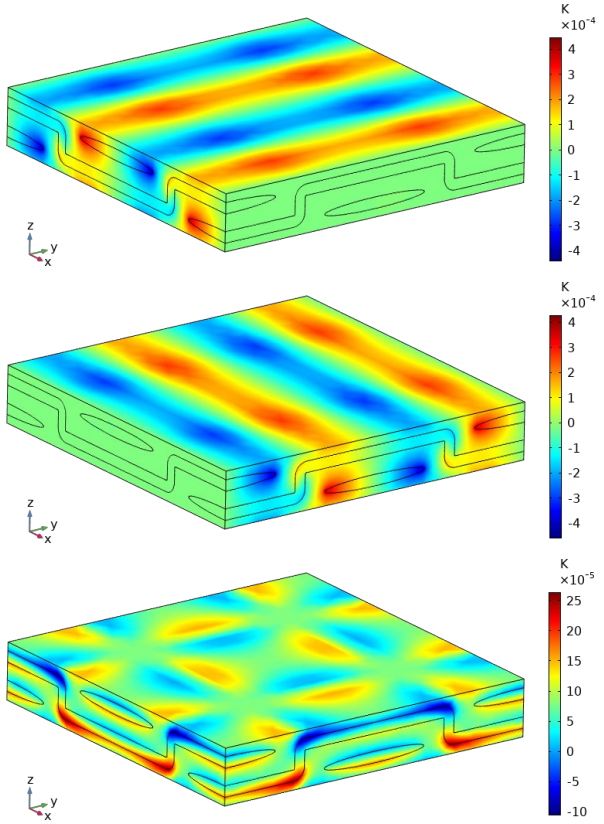
$\Rightarrow \approx \mathbf{10^9}$ **DOF to solve for !!**

→ **We must rely on a more sophisticated approach: *e.g.* periodic homogenization method!**

II. Modelling and Numerical Model

- **Principles of the periodic homogenization method**

Step 1: submit the microstructure to unitary solicitations (FEM computations)



e.g. $\approx 100\ k$ DOF/computation

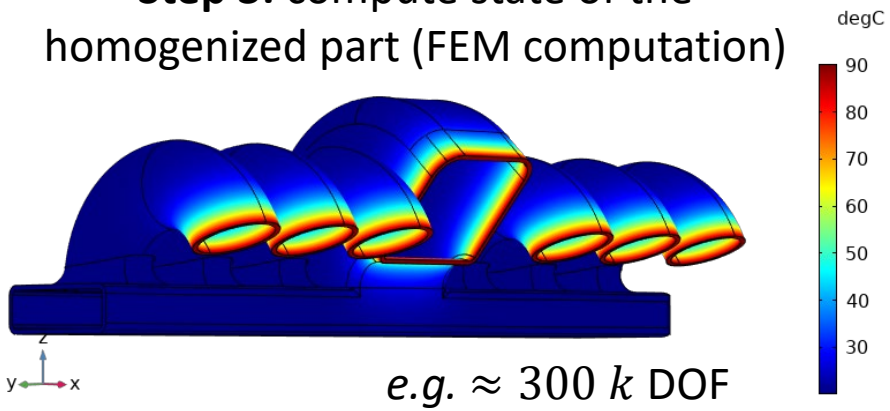
Step 2: compute homogenized properties (post-treatments)

→ *Conductivity matrix*

→ *Elasticity tensor*

→ …

Step 3: compute state of the homogenized part (FEM computation)



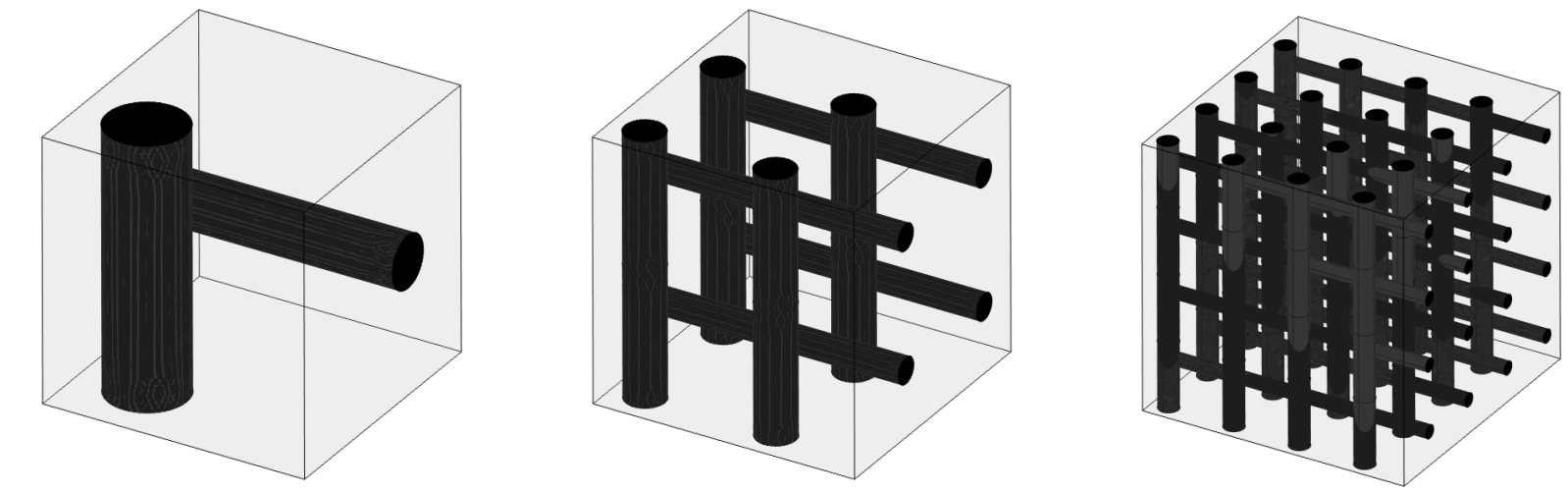
e.g. $\approx 300\ k$ DOF

Step 4: relocate → combine macroscopic and microscopic results to **get accurate results at microscale** (post-treatment)

II. Modelling and Numerical Model

- **Theoretical results of the periodic homogenization method**

\+ Size of the unit cell -



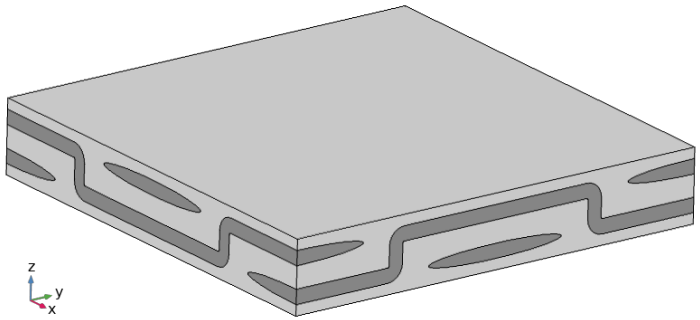
\- Accuracy of the method (theoretically guaranteed!) +

Identical computational cost !

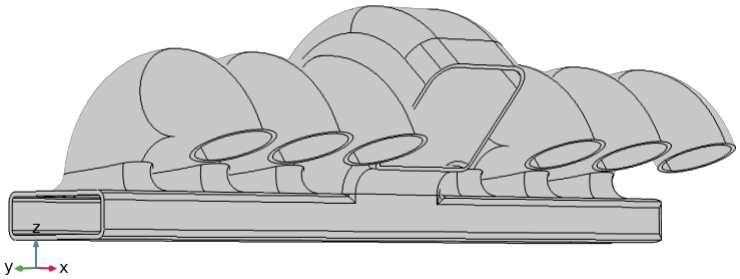
II. Modelling and Numerical Model

- **COMSOL implementation**

Component 1: microstructure analysis



Component 2: macrostructure analysis



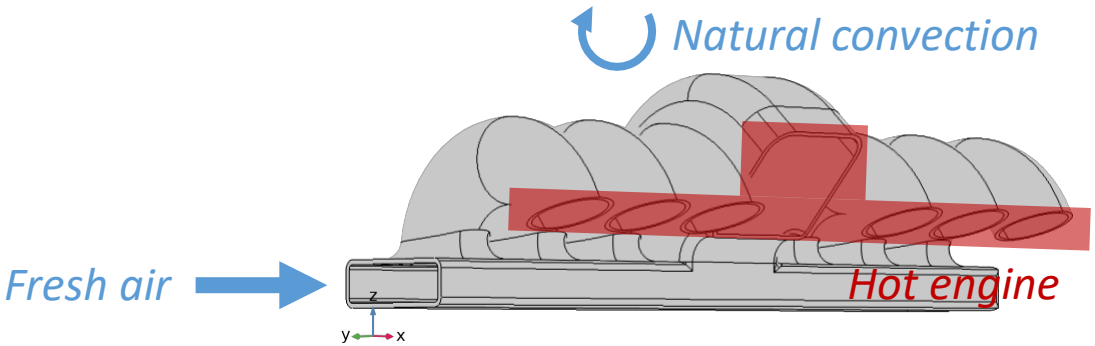
Non-exhaustive practical issues :

- ❑ Non-conventional system of PDEs
- ❑ Numerical care is needed: meshing, discretization orders…
- ❑ Automation required to implement *long* formulas

→ COMSOL Multiphysics® is flexible enough for that!

III. Main Results

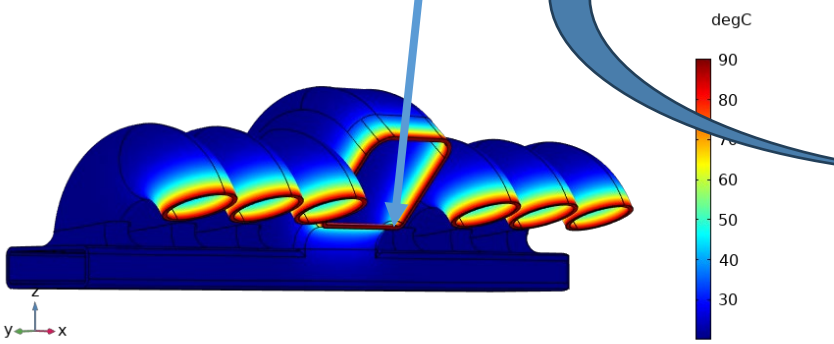
- **Application to heat transfers**



Goal: preventing delamination
→ maximal thermal gradient?

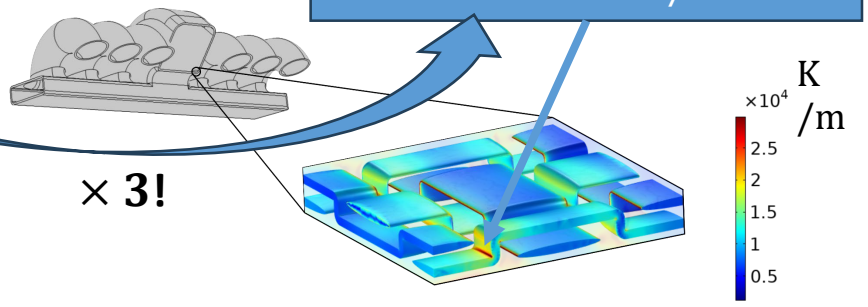
Apparent gradient

$\max \|\nabla T_{homogenized}\| = 1.02 \times 10^4$ K/m



Microscopic gradient

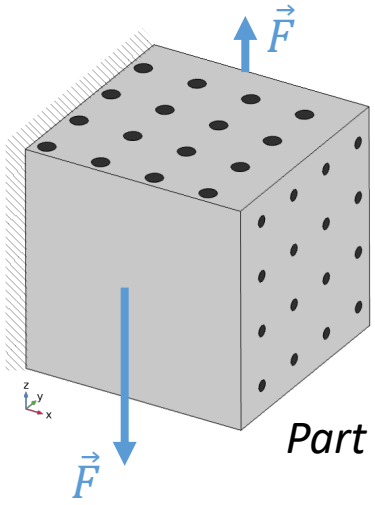
Local max $\|\nabla T_{relocalized}\| = 2.98 \times 10^4$ K/m



→ **Only looking at homogenized variables may not be sufficient!**

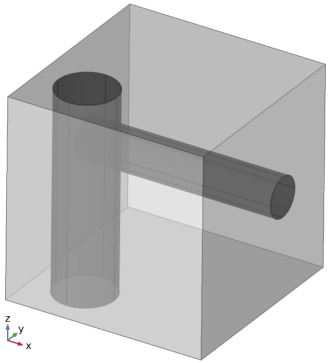
III. Main Results

- **Application to solid mechanics**



Part

= repetitions of



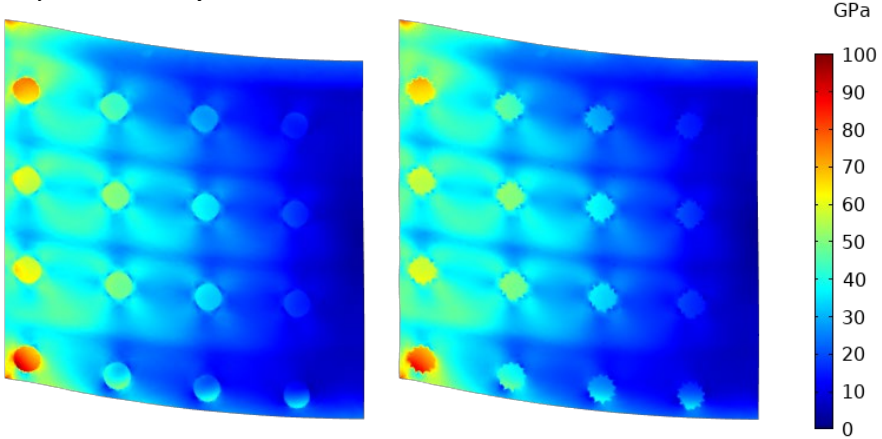
Unit cell

→ Mechanical stress within the part?

Direct FEA
1,8 M DOF/33 min

Periodic homogenization
0,3 M DOF/2.5 min

Von Mises stress within a cut plane



→ **The method is very accurate!**

→ **The method is very efficient!**

IV. Conclusions - Perspectives

→ Understanding and predicting the microscopic behavior of parts made of microarchitectured materials is important to design them

→ Periodic homogenization is one of the techniques making the numerical analysis affordable and accurate

→ **Major contribution:** generic implementation within COMSOL Multiphysics® for:
- ❑ Heat transfers by conduction
- ❑ Solid mechanics

→ What about next steps?
- ❑ Handling more physics: *e.g.* studying porous media at the microscale
- ❑ Dealing with nonlinearities
- ❑ Applying the method to more industrial cases!

To finish…

Thank you!

Q&A?

Our question: What about a coffee to discuss your topic? ☺







Frédéric Viry
SIMTEC (+33) (0)9 53 51 45 60
frederic.viry@simtecsolution.fr

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