Karlsruhe Institute of Technology

COMSOL CONFERENCE 2016 MUNICH

IHM

# Model of microwave assisted thermal adhesion of synthetic leather to a plastic substrate

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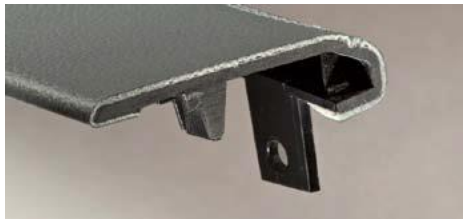
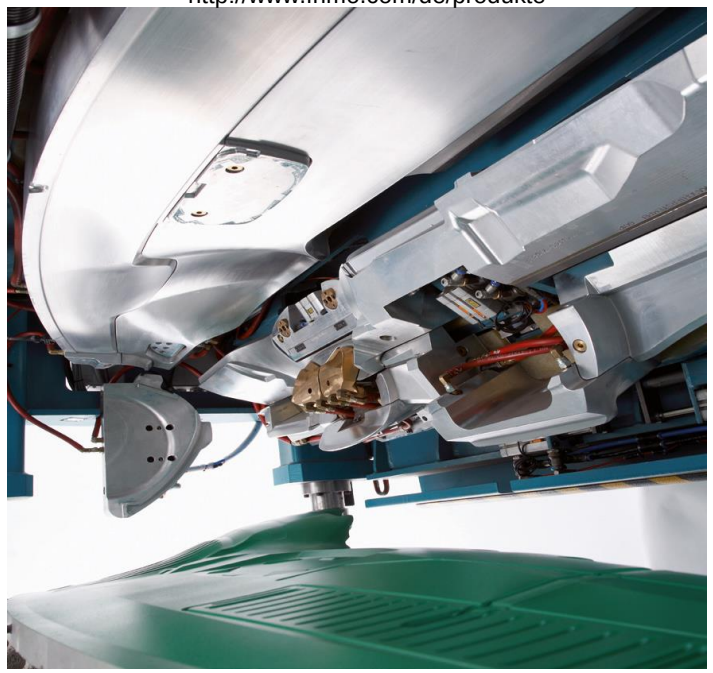


# Outline

- Motivation
- Materials dielectric characterization
- Electromagnetic modelling
- Heat transfer model (COMSOL)
- Optimization
- Conclusions

http://www.frimo.com/de/produkte



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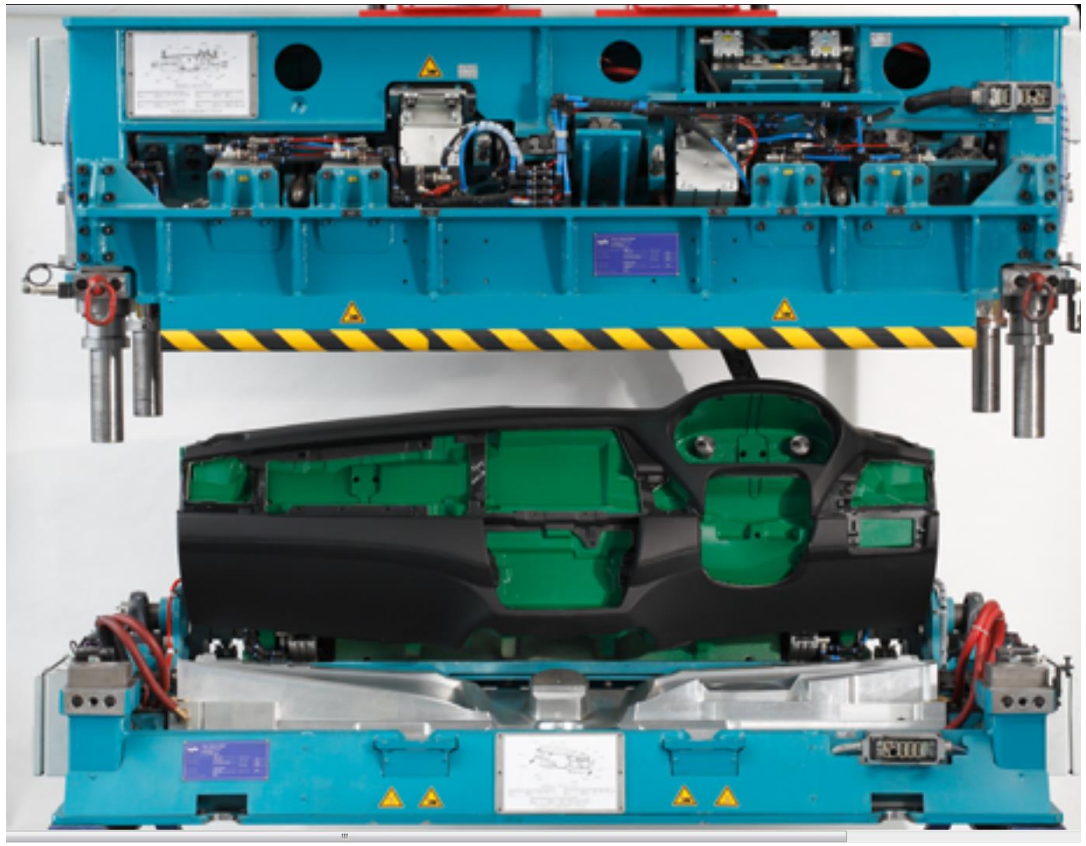
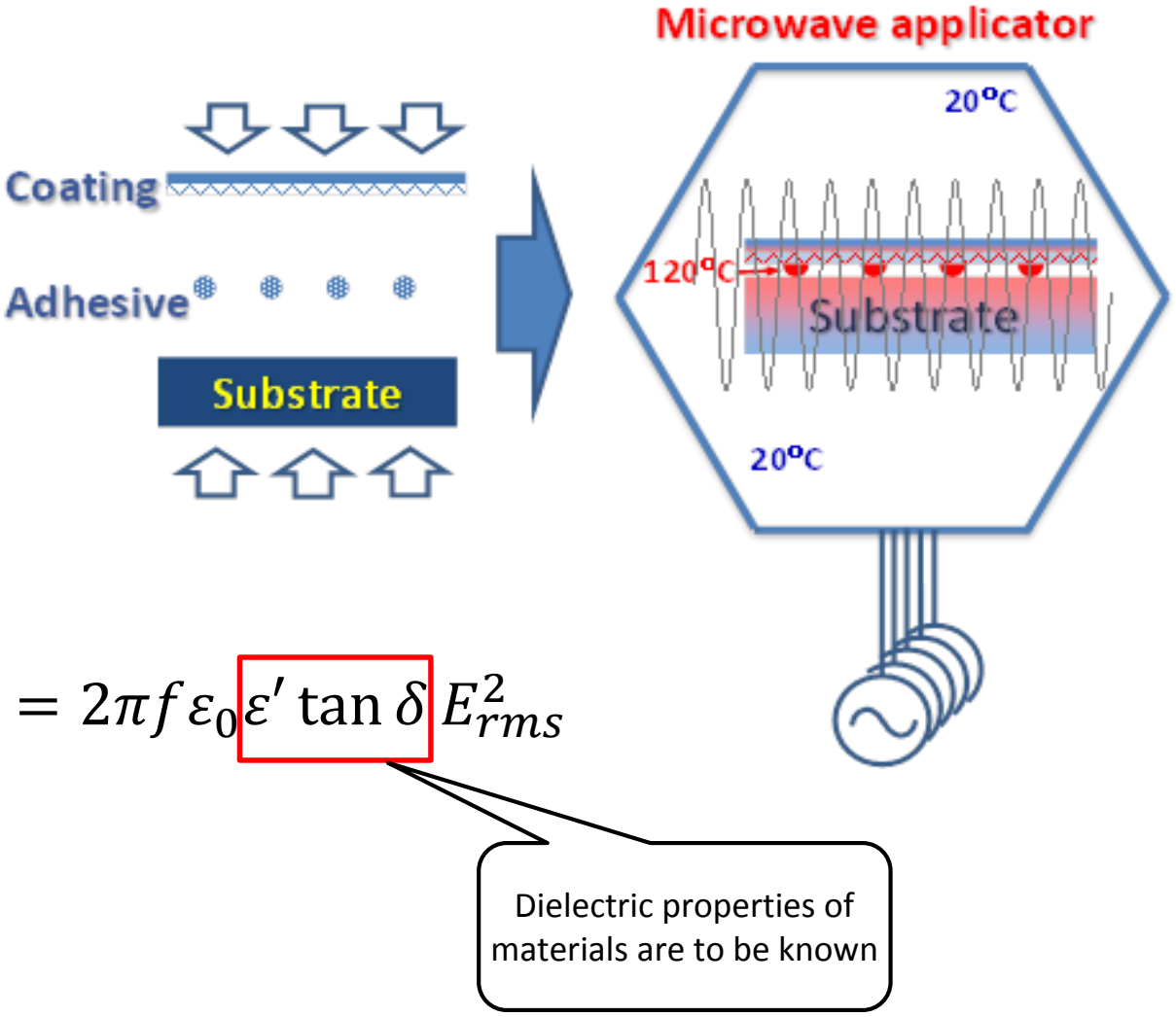


# Motivation





HEPHAISTOS Oven

http://www.voetsch-ovens.com/en/products/industrial_microwave_system/schunk01.c.59509.en

$$P_{abs} = 2\pi f \varepsilon_0 \varepsilon' \tan\delta \, E_{rms}^2$$

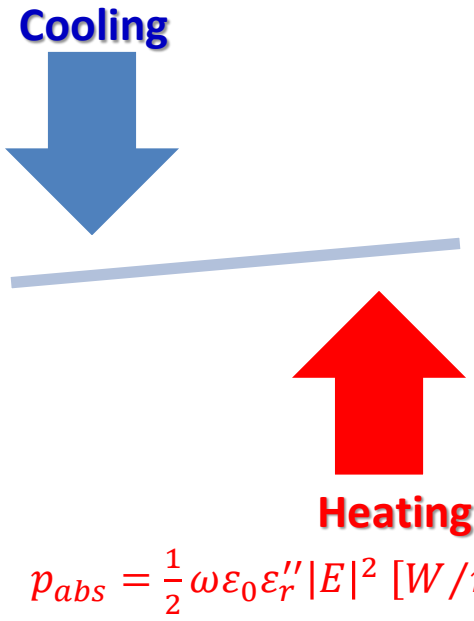
Dielectric properties of materials are to be known

# Heat balance

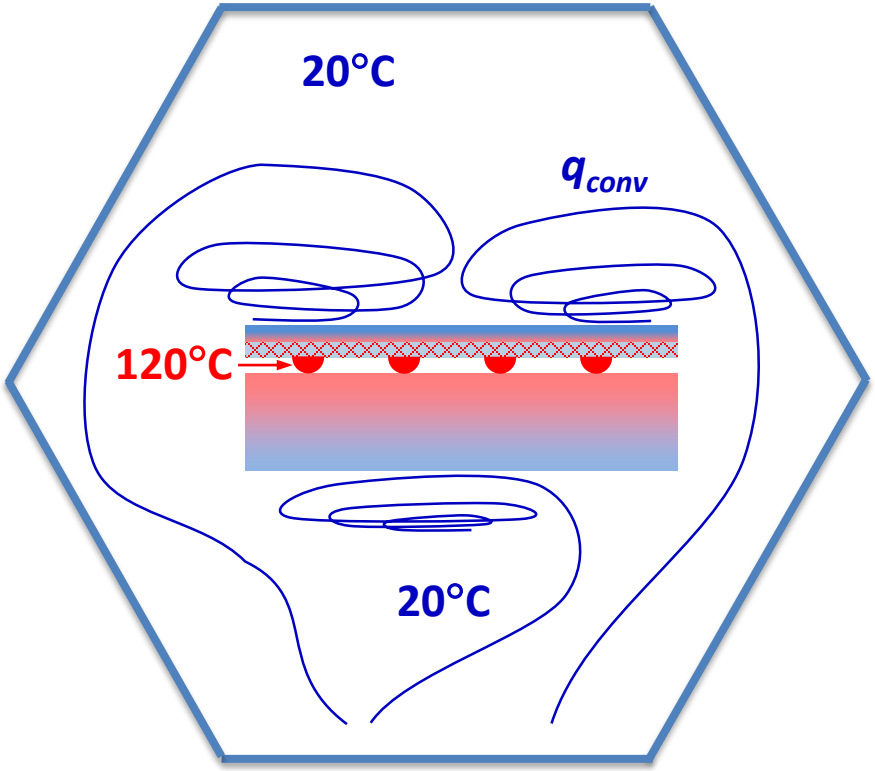
Heat source

$$\rho C_p \frac{\partial T}{\partial t} = \nabla \cdot (k \nabla T) + p_{abs}$$

$$q_{conv} = h\left(T_{surf} - T_{air}\right)[W/m^2]$$




$$p_{abs} = \frac{1}{2}\omega\varepsilon_0\varepsilon_r''|E|^2\ [W/m^3]$$



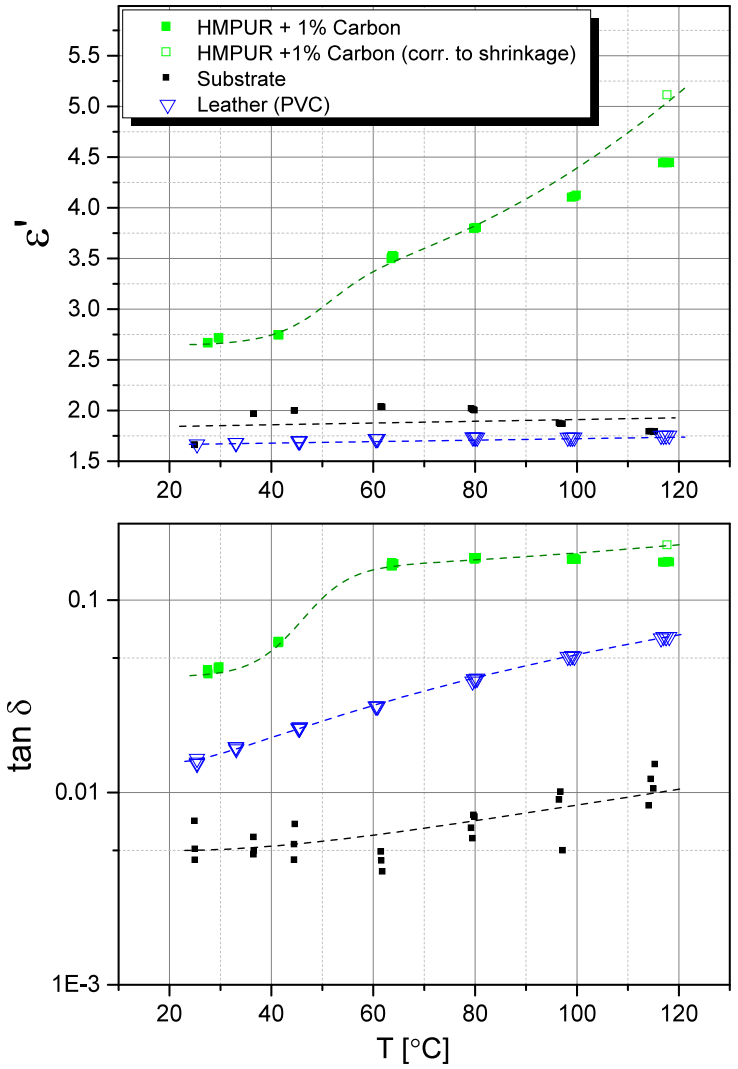
# Materials dielectric properties versus temperature

## Materials:

- → **Adhesive**: Hot melt polyurethane (HMPUR) blended by carbon particles
- → **Substrate**: ABS-PC
- → **Coating**: artificial PVC leather with textile layer at wrong side

Materials were characterized with cavity perturbation method and within working temperature range

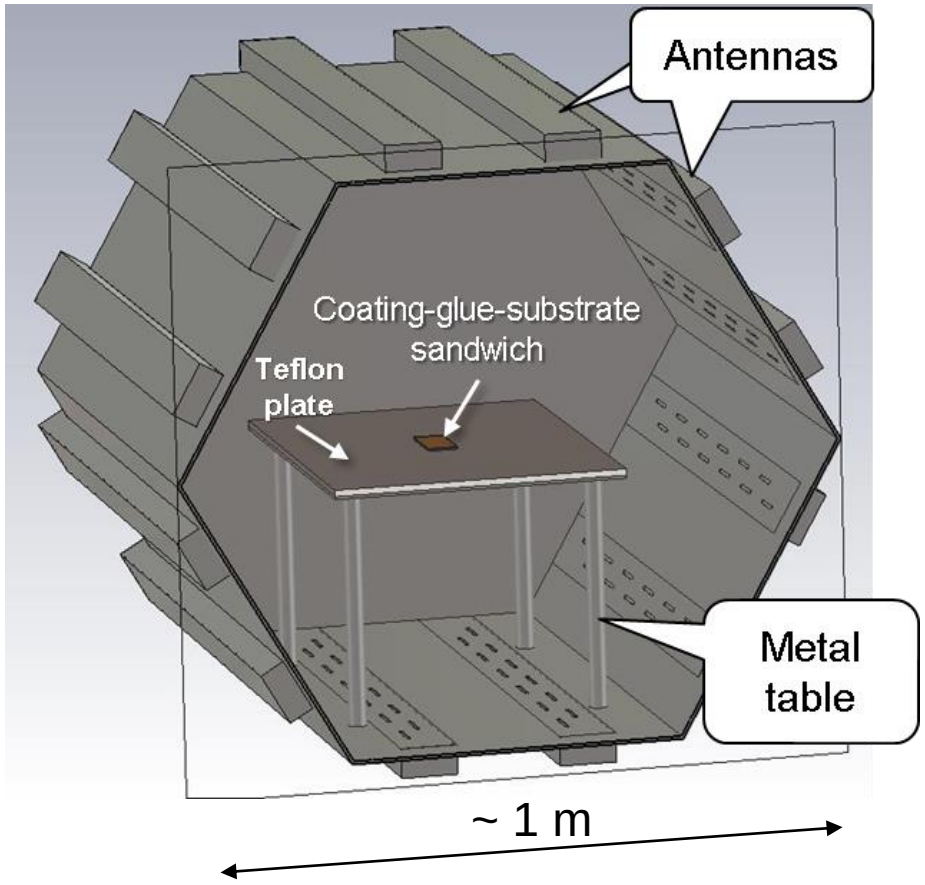
➔ Absorption of microwaves in adhesive is predominated!



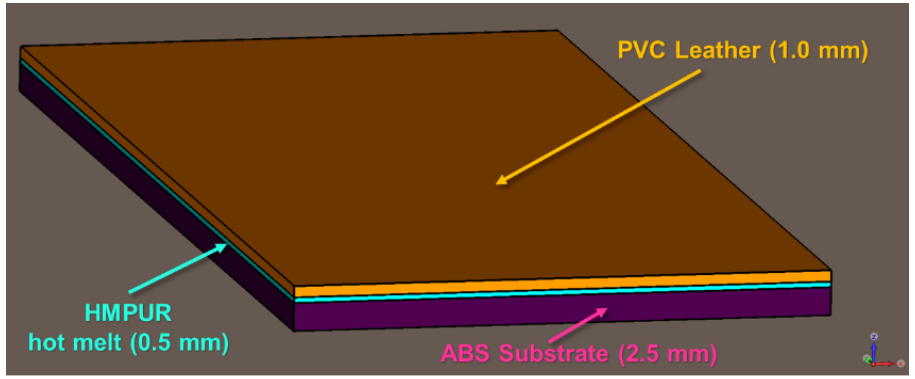
# Electromagnetic Modelling (CST μwave Studio.)

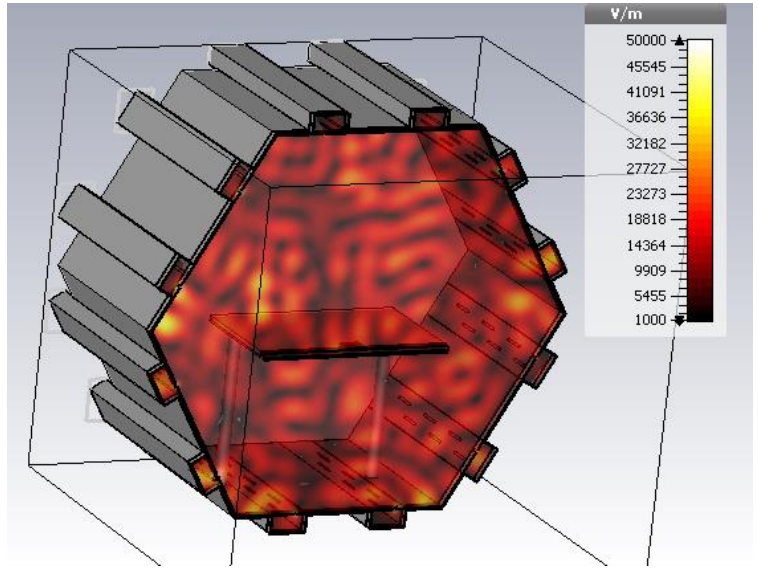
➔ The aim – to find dielectric heat sources in every material

Geometry of task.




Coating-glue-substrate sandwich




Electric field pattern.

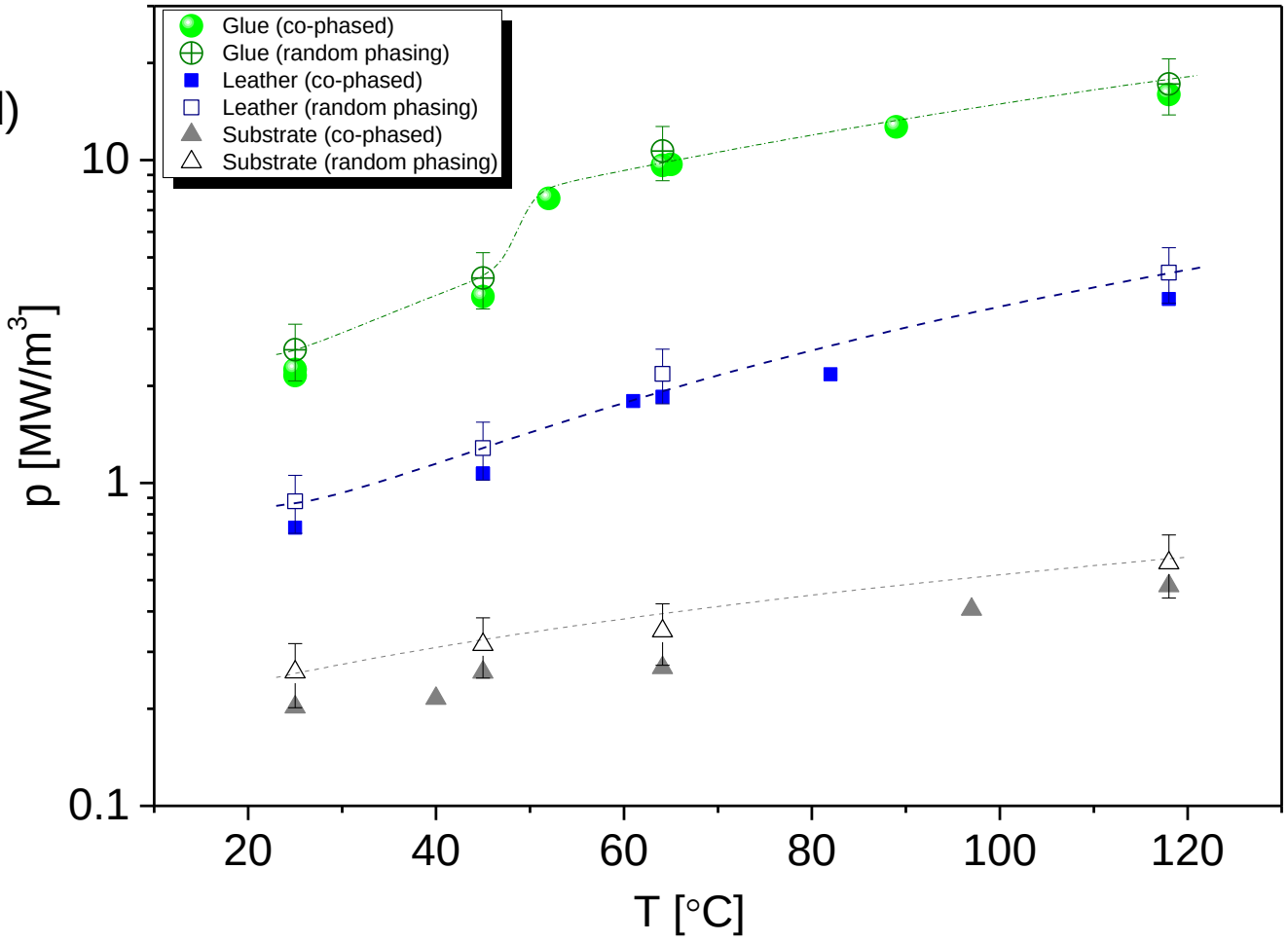
# Absorbed microwave power density.

The cross-link between antennas is negligable

➔ magnetrons are independent (not locked)

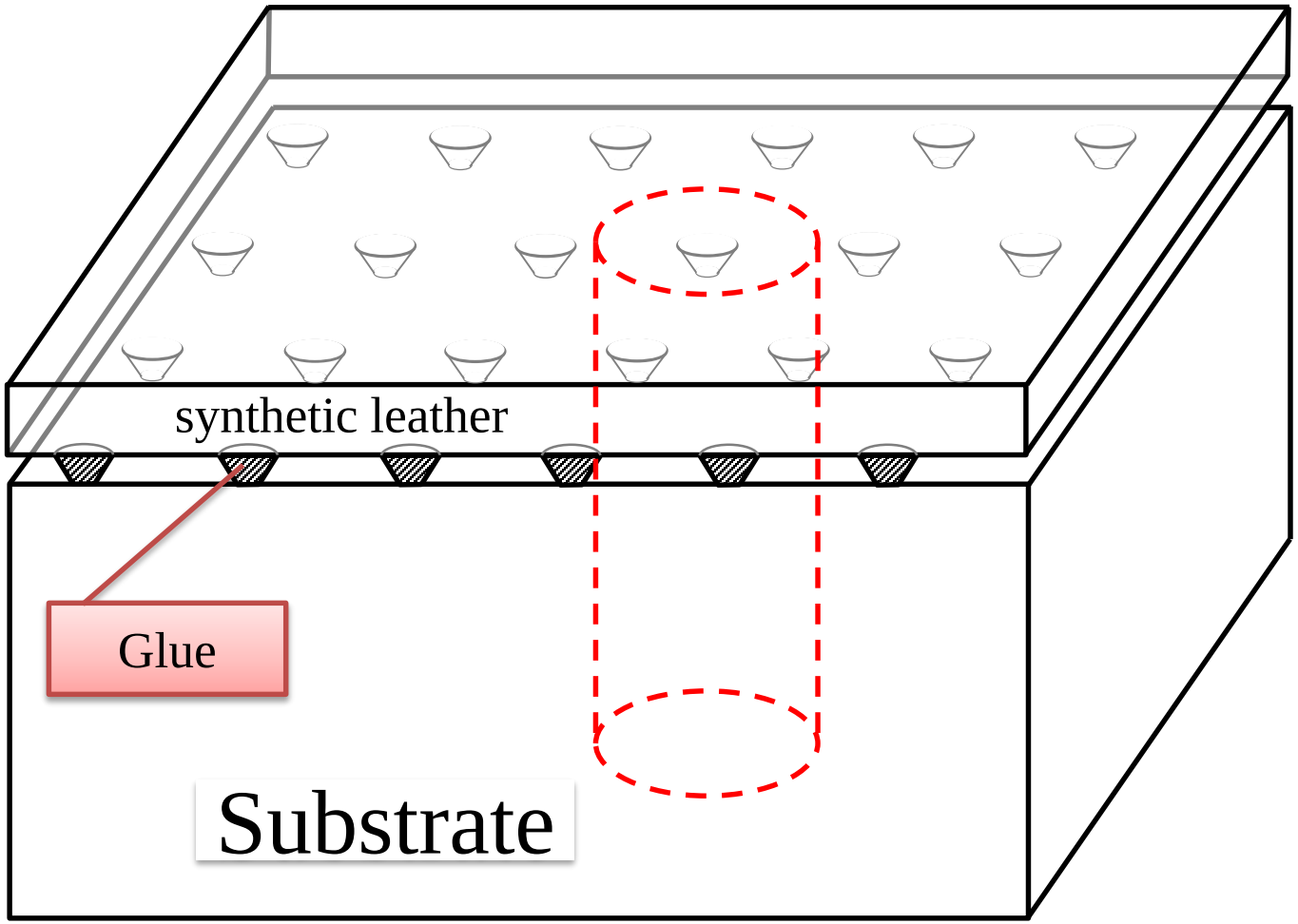
➔ the phasing is random

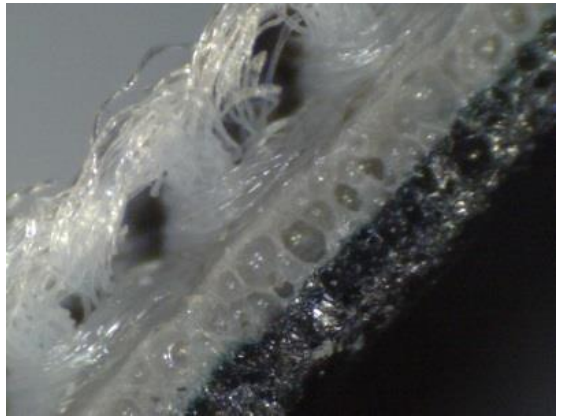
➔ f=2.45 GHz



# Heat transfer problem (COMSOL ®)

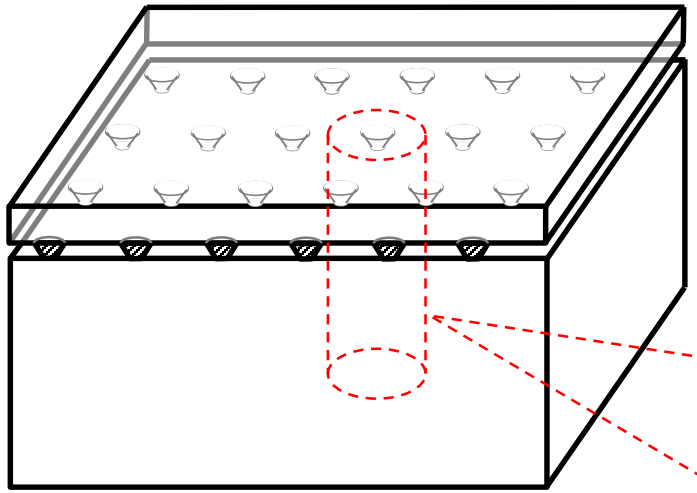
# Geometry

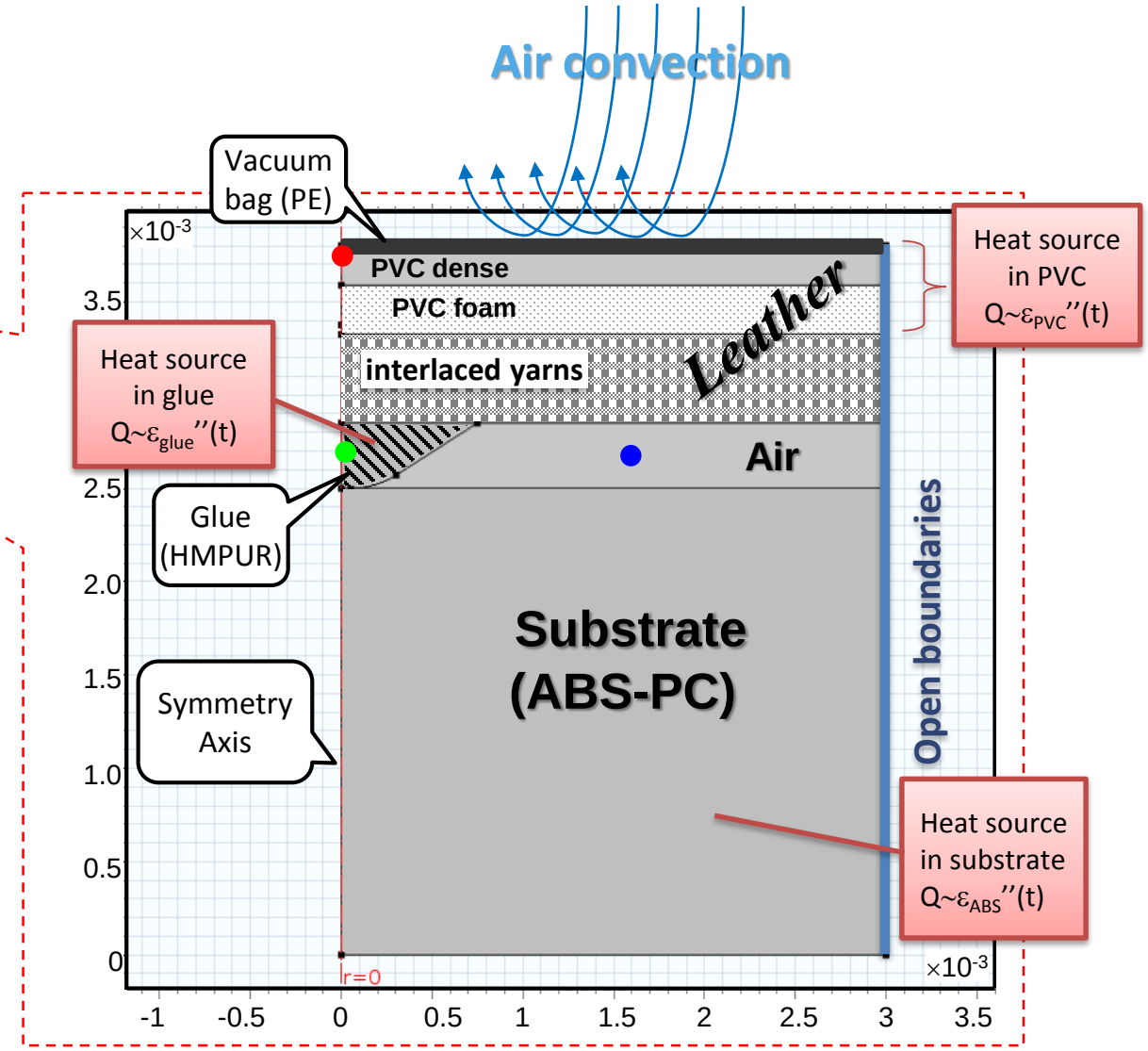



The glue is patterned to cover a selected percentage of surface.
Restrict a geometry to a single glue volume.
Neglect the influence of neighboring glue volumes.

# Heat transfer model (COMSOL®)

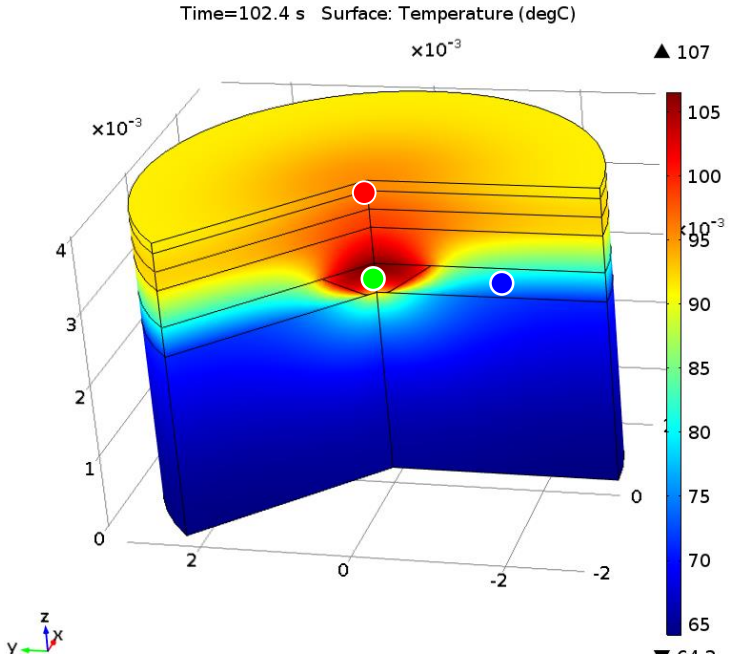




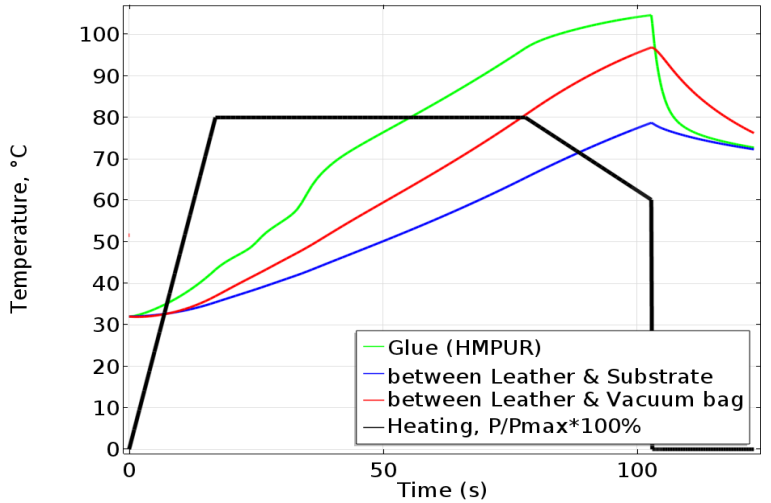
# Properties of materials in the model

| Domain name | Density $\rho$ [kg/m$^3$] | Specific heat $c_{p,}$ [J/kg/K] | thermal conductivity $k$ [W/m/K] | Latent heat [J/kg] | Thickness along Z [mm] |
|---|---|---|---|---|---|
| PVC dense [7] | 1200 | 1800 | 0.15 | | 0.2125 |
| PVC foam | 800 | 900 | 0.10 | | 0.2125 |
| Interlaced yarns [8] | 200 | 1200 | 0.04 | | 0.475 |
| Glue [5] | 950 | 1500…1700 | 0.19 | $5*10^4$ | 0.35 |
| Substrate (ABS)[6] | 1080 | 1300 | 0.19 | | 2.5 |
| Air | 1 | 1000 | 0.026 | | 0.35 |

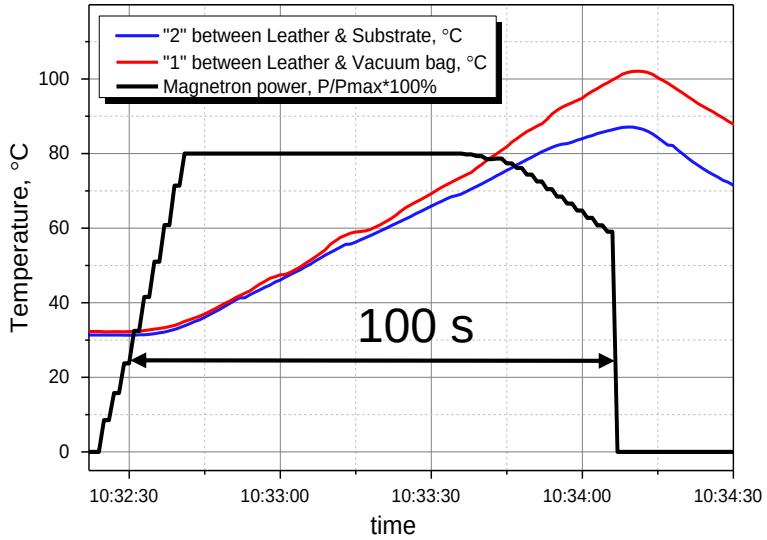
# Heat transfer model with COMSOL® (II)




$\Delta t_{HEAT}$=102 s
h=7 W/K/m$^2$ (natural convection)
$p_{abs}$=2.5… 15 MW/m$^3$
$k_{interlaced\ yarns}$= 0.04 W/m/K




Model

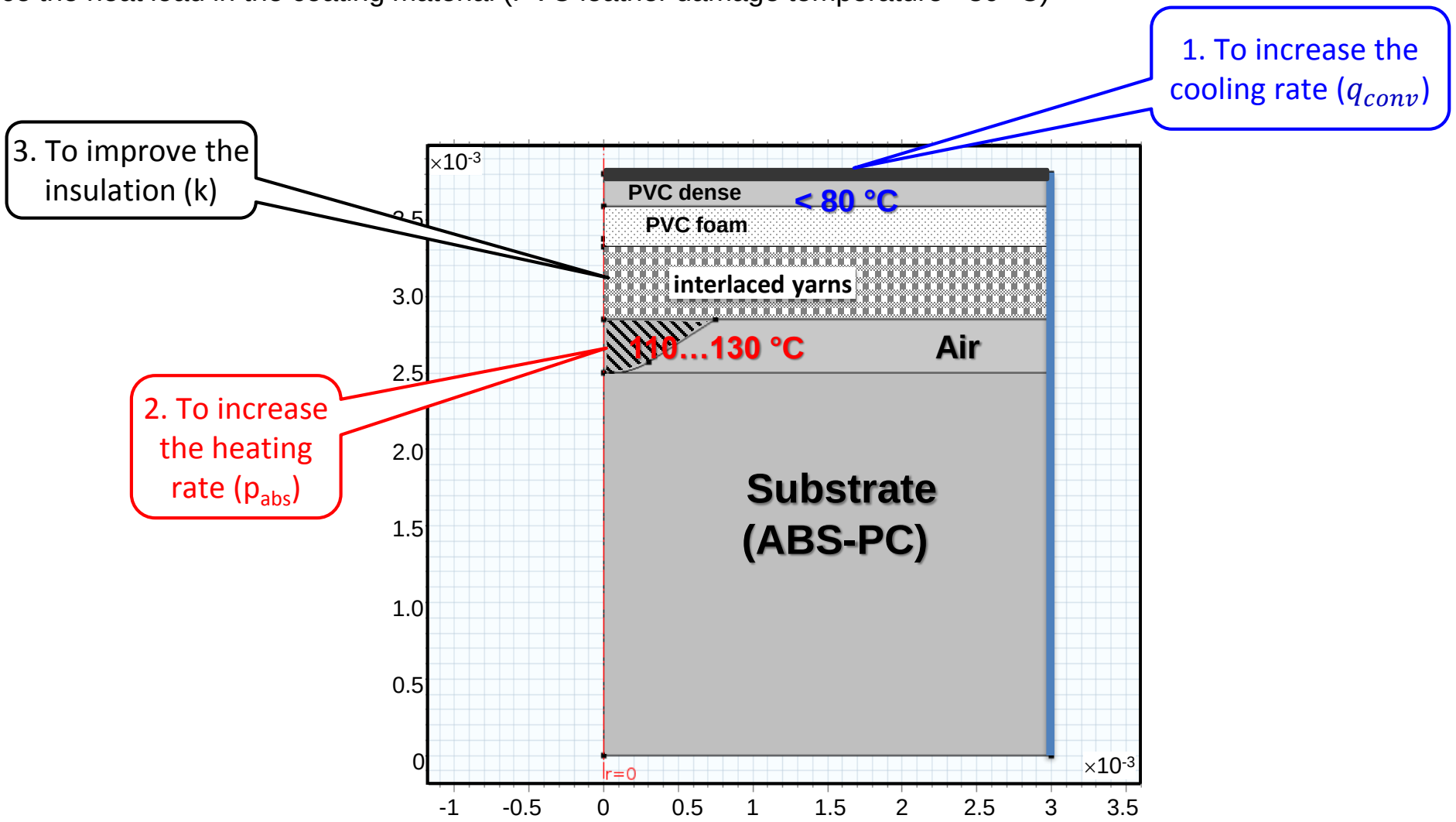



Experiment

➔ Model describes satisfactory the experiment
➔ Note: thermocouples are slow as compared with „ideal“ temperature in the model

# Optimization of process

- To decrease the time of heating (below 60 s), but reach the melting point in glue! (~120 °C)
- To reduce the heat load in the coating material (PVC leather damage temperature ~80 °C)



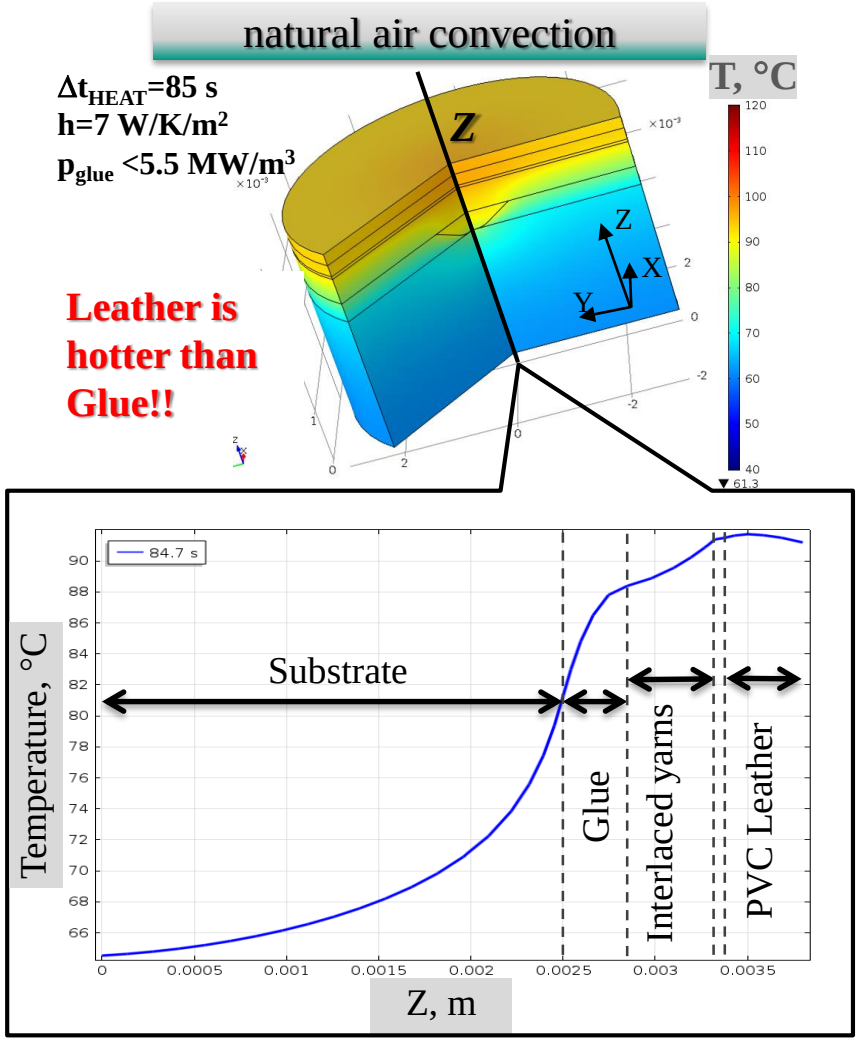
# Optimization: absorbed power and surface cooling

- reference case

natural air convection

$\Delta t_{HEAT}$=85 s
h=7 W/K/m$^2$
$p_{glue}$ <5.5 MW/m$^3$

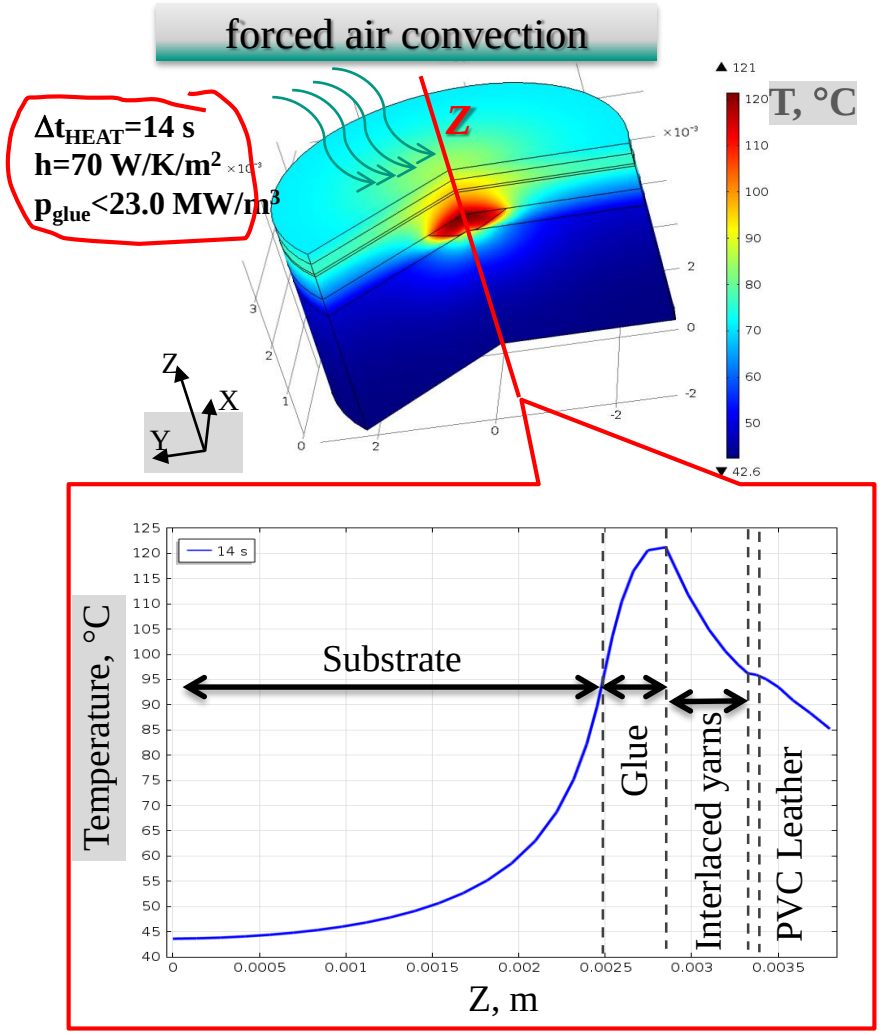
**Leather is hotter than Glue!!**




- optimized

forced air convection

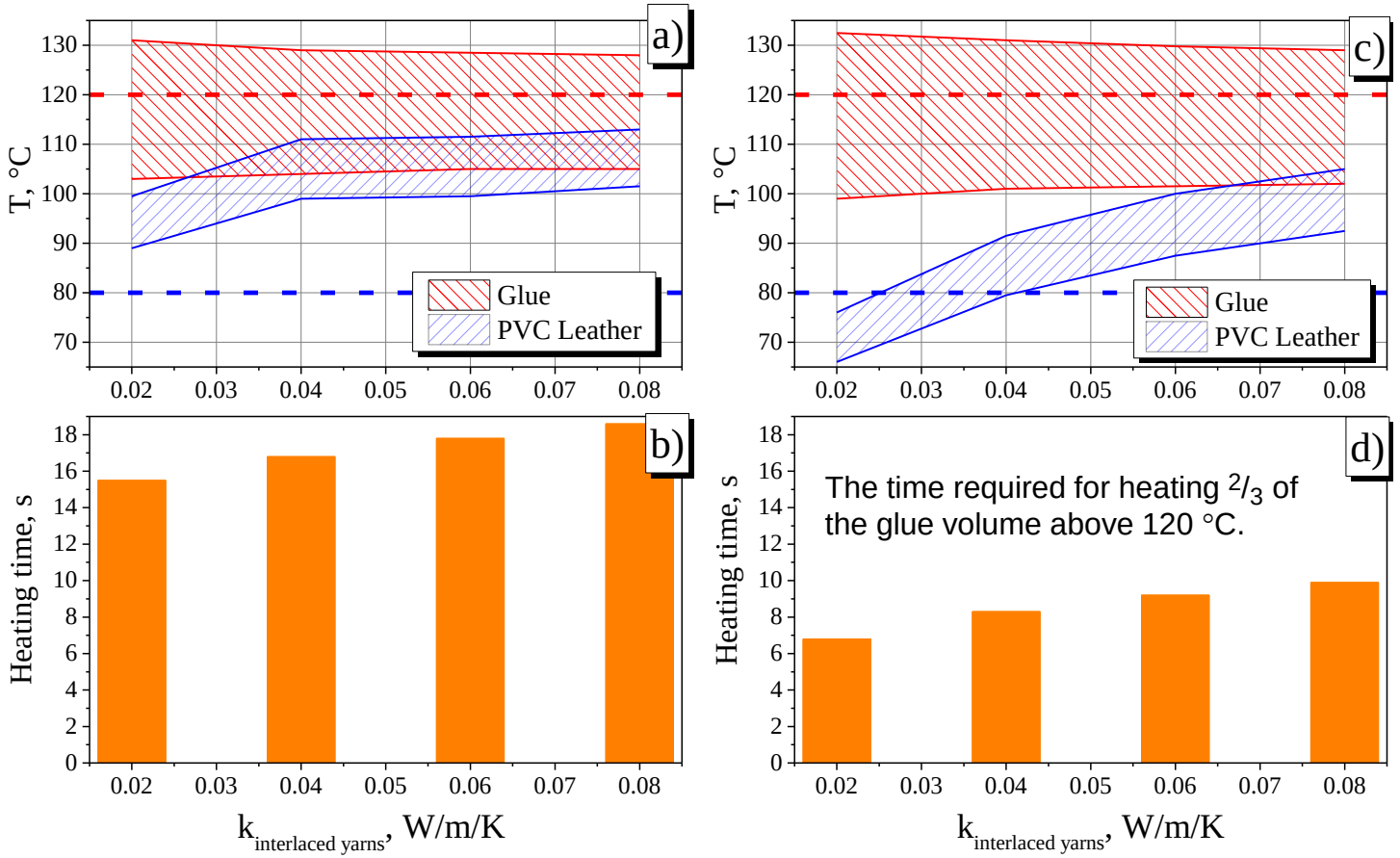
$\Delta t_{HEAT}$=14 s
h=70 W/K/m$^2$
$p_{glue}$<23.0 MW/m$^3$



# Optimization: heat conductivity of textile layer

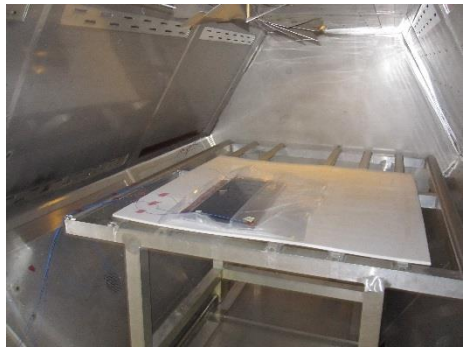
- $p_{glue} < 23\ MW/m^3$
- $h = 70\ W/K/m^2$

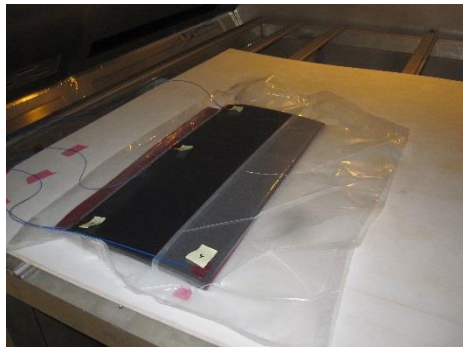
- $p_{glue} < 30\ MW/m^3$
- $h = 70\ W/K/m^2$

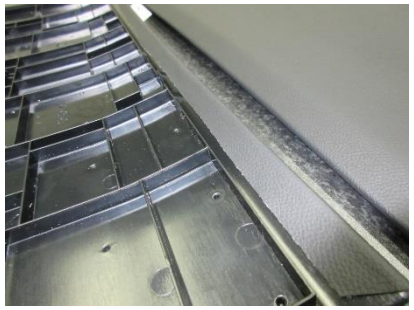



- Temperature gradient is more dependent on the absorbed power in glue, $p_{glue}$.
- The heating time is dependent both on k and $p_{glue}$

# Coating of a cover of the glove box of *Land Rover*



# Conclusions

- **Microwave assisted bonding** of PVC artificial leather to the plastic substrate **is possible** but requires the optimization of the process and materials.
- Such an **optimization is inevitable without numerical modelling** which gives us the understanding how and where the energy is absorbed, how it is transferred and dissipated in materials.
- Optimization of
  **absorbed microwave power** (loss factor of glue),
  **heat sink** at the leather surface and
  **fabric layer** insulating properties
  allow to reach the melting temperature in the hot-melt glue keeping the coating material below its damage temperature.

# Thank you for your attention!

**ACKNOWLEDGMENTS**

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