Microwave processing of a laminated part: application to Glass Fiber Reinforced Polymer (GFRP)

H. Tertrais[1,2], R. Ibanez[2], A. Barasinski[1] and F. Chinesta[2]

[1]GEM, UMR CNRS - Centrale Nantes
Hermine.Tertrais@eleves.ec-nantes.fr Anais.Barasinski@ec-nantes.fr
[2]High Performance Computing Institute, Centrale Nantes
1 rue de la Noe, BP 92101, F-44321 Nantes cedex 3, France
Francisco.Chinesta@ec-nantes.fr

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INTRODUCTION

Composites parts tend to represent an increasing volume of production in transport industry due to their combination of high mechanical properties and low mass.

Inversely to traditional heating methods that depend on surface heat transfer and induce long cycle time, microwave (MW) technology relies on volumetric heating which enables better process temperature control [1] and less overall energy use, this can results in shorter processing cycles. The main drawback of this technology today is that the complex physics involved in the conversion of electromagnetic energy to thermal energy is not entirely understood and controlled.

The principal objective of this work is to model the interactions of the MW field with the composite material at micro and meso-scales, in order to simulate the way in which electromagnetic energy is converted to thermal energy within the material volume and the various interfaces. The main challenge concerns the high-resolution description of the electromagnetic and thermal fields in a composite laminate, that involve plies whose characteristic in-plane dimension is orders of magnitude higher than the ones related to the thickness (typical aspect ratio are of tens of thousands) (see Fig 1 left).

PROCESS AND METHOD DESCRIPTION

The composite part to be heat is made of a GFRP, practically transparent to microwaves, it is placed on a bench, in a tool made of a material transparent to MW but coated in its interior surface by an absorbent layer. The whole is placed in an oven cavity with a hexagonal shape, as a Hephaïstos© one.

A coupled thermal and electromagnetic model is proposed in order to simulate the composite materials heating. In that situation the use of in-plane-out-of-plane separated representations within the Proper Generalized Decomposition -PGD- framework, allows writing the electric field, using the Hadamard product, as:

$$\mathbf{E}(x,y,z) = \sum_{i=1}^{N} \mathbf{X}_i(x,y) \circ \mathbf{Z}_i(z)$$

Such a separated representation seems an appealing and valuable route for solving 3D models, very rich in both, the in-plane and the out-of-plane directions, while ensuring a computational complexity of standard 2D models [2 -3].

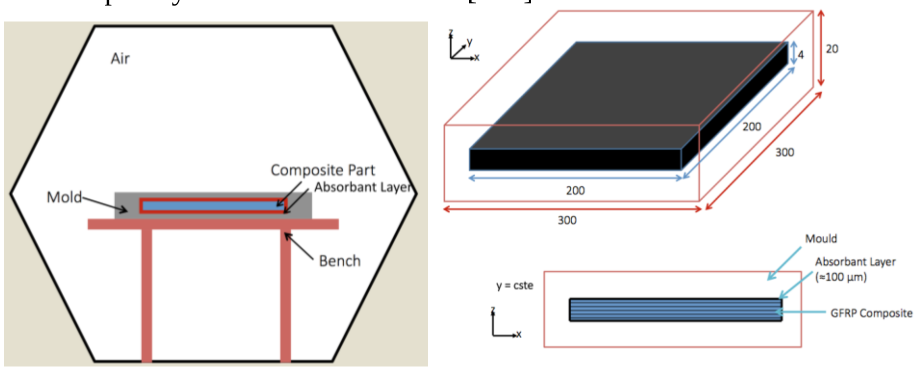
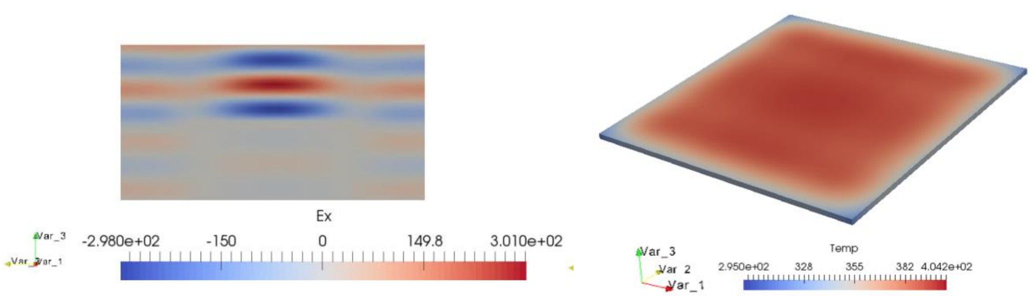


Figure 1. Schematic representation of the process (left) and zoom of the mould and composite part with its characteristic dimensions in mm (right).

TEST CASE

We consider a domain made of GFRP (of dimension 4x200x200mm), surrounded by an absorbent box (100µm thick), and the whole surrounded by air (see Fig 1 right). The material properties of the absorbent layer and the GFRP are respectively the following: $\varepsilon_r = 5$, $\sigma = 10^{-4}$, $a = 3.10^{-5}$; and $\varepsilon_r = 50$, $\sigma = 100$, $a = 10^{-4}$; with respectively the permittivity, conductivity (S/m), and thermal diffusivity (m^2/s), the permeability μ is always 1. The mesh is composed of 100x100 elements in the in-plane and 200 elements in the thickness direction. Figure 2 left depicts the electric field component E_{xx} evolution in the domain, and Figure 2 right, the associated temperature evolution after 1min.



(a) (b)

Figure 2. Electric field component Ex in the middle cross section of the whole domain (a) and Temperature evolution in the composite part (in Kelvin) after 1min (b)

CONCLUSION

In the present work, a simulation tool is presented, allowing the calculation of the EM and thermal fields in the domain of interest, here being the composite part and mould domain placed into the oven cavity. These fine solutions will allow a better understanding of the thermal history experienced by the composite part during the heating stage in the microwave oven, and better defined the thickness of the absorbent layer, as well as the most appropriate material parameters by inverse engineering.

REFERENCES

[1] G. Hug. (2005). "Behavior analysis of carbon-epoxy laminates under high-speed loading: manufacture of the same materials by means of microwave curing for comparison," Ph.D. thesis, Arts et Métiers ParisTech.
[2] B. Bognet, A. Leygue, F. Chinesta, A. Poitou and F. Bordeu (2012). Advanced simulation of models defined in plate geometries: 3D solutions with 2D computational complexity, Computer Methods in Applied Mechnanics and Engineering, 201, 1-12.
[3] F. Chinesta, R. Keunings, A. Leygue. Proper Generalized Decomposition for Advanced Numerical Simulations. A primer. Springerbriefs, Springer, 2014.