EFFICIENT MULTISCALE METHOD TO SIMULATE LIQUID RESIN INFUSION PROCESS IN FABRICS WITH QUASI-PERIODIC PERMEABILITY

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Introduction

Liquid Resin Infusion (LRI) is a popular technique to manufacture large structural composite parts, such as wind blades. Recent work by Yun et al. [1] showed that the manufacturing quality is strongly affected by uncertainties in material properties, namely inter-tow pore size. Air pockets can be created as a result of through-thickness flow in woven fabrics that are not periodic in their weaving pattern. Air pocket's size and location have been predicted through a stochastic modeling of geometrical defects with deterministic Darcy's flow solver [1]. While that approach is suitable for limited-size parts, the development of efficient methods to study stochastic phenomena involving very different scales in very large domains remains a key challenge. The fine spatial discretization required leads to high computational cost, particularly when considering stochastic problems.

We propose a new numerical method designed to reduce the cost of such simulations compared to direct resolution by finite element method. It can address heterogeneous media with correlated or uncorrelated local perturbations. The potential of the proposed method is first demonstrated on 2D stationary diffusion problems and is extended to transient diffusion case. It exploits the quasi-periodicity of the fabric's structure to compute a cost-efficient low-rank approximation of the field of interest (i.e. temperature or pressure), identified as a tensor in a two-scale representation. Even if the case under consideration here is characterized by a weak random periodicity loss, this technique is found relevant even for loosely structured materials [3].

Multi-scale Low-Rank Method (MsLRM)

The proposed numerical method is based on a two-scale representation allowing a tensor-structured formulation of the problem which exploits the recurrence of microscopic patterns through low-rank approximation techniques. A discontinuous Galerkin formulation is used. A greedy algorithm computes these low-rank approximations with controlled relative residual error. Details about this method can be found in [2-3].

Stationary diffusion test case

We consider the stationary diffusion problem that reads

$$-\nabla \cdot (\boldsymbol{K}\nabla T) = 0 \tag{1}$$

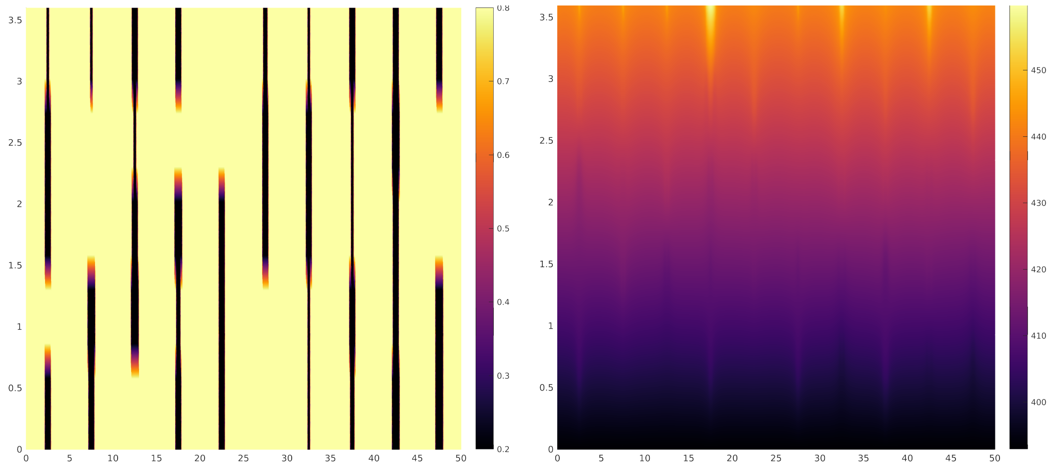
where **K** is the conductivity tensor and T is the temperature.

The computational domain is of physical dimension 530 x 36 mm^2. It is meshed with a multi-scale mesh with quadrilateral elements. The coarse grid, corresponding to the weaving pattern, is meshed with 530 (130 x 5) elements, each cell of that grid being meshed with 250 (50 x 5) quadrilateral elements. Hence, the overall mesh is made of 132 500 elements.

A constant flux of 10 W/m^2 is applied on the top side, a zero-flux condition is assigned for the two lateral sides and a constant temperature of 373K is imposed on the bottom side. The inter-tow resin pocket size distribution is given in Table 1. For the sake of clarity, only the thermal conductivity map of a small area is presented in Figure 1a). The total computation time for the direct FEM is 1404s (Figure 1b), compared to 1.6s for the MsLRM method (Figure 2a) on an Intel® Core^{TM} i7 3.40 GHz processor. The very small difference between the MsLRM and the direct FEM is shown in Figure 2b).

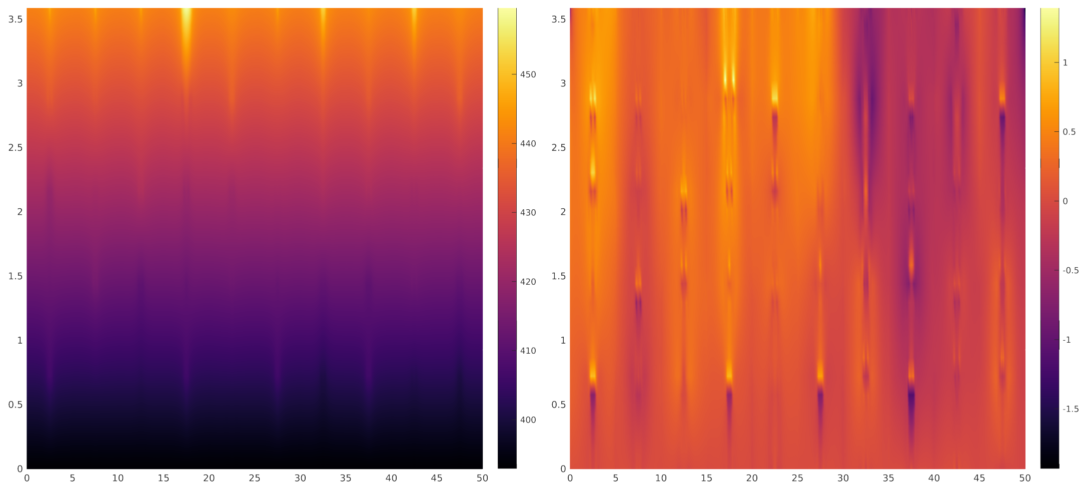
Table 1: *Dimension and probability of occurrence of inter-tow resin pocket size*

Radius (mm)	0	0.052	0.115	0.179	0.242	0.305	0.369	0.432	0.495	0.558	0.622
Probability	0.192	0.058	0.072	0.143	0.141	0.197	0.116	0.062	0.009	0.005	0.005



a) b)

Figure 1: a) *Thermal conductivity map on a small area. Darker zones correspond pure resin zones of different size, b) FEM solution*



a) b)

Figure 2: a) MsLRM solution b) *Difference between the MsLRM and the direct FEM computations of the small area in Figure 1a)*

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