

QUANTITATIVE COMPARISON BETWEEN FAST FOURIER TRANSFORM AND FINITE ELEMENT METHOD FOR MICROMECHANICAL MODELING OF COMPOSITE

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ABSTRACT

A variety of numerical methods can be applied for multi-scale simulation of composite materials in general and textile reinforced composites in particular. Among numerical methods, the Finite Element Method (FEM) is the main tool for modeling textile composites [1]. Recent developments have brought increased interest in the Fast Fourier Transform (FFT) based method for multi-scale material modeling. This method uses image-based techniques and also gives accurate results as FEM voxel-based models do [2]. Backing to 1994, the FFT method was proposed initially by P.Suquet and H.Moulinec [3], as a voxel-based methodology that does not need stiffness matrix assembling like FEM. It can thus be very efficient in the field of digital materials and easily parallelized. The main drawback of voxel-based models is the presence of strong oscillations due to the non-smooth interface [4]. From the best of our knowledge, the FFT and FEM are often compared in a general way. In this work, specific problems of the micromechanics of composite materials were addressed in order to compare quantitatively FFT and FEM solutions of the stress field at the interface, based on the direct output and with the introduction of a smoothing method. The open-source software AMITEX [5] is applied for all FFT calculations and ABAQUS is applied for all FEM calculations.

Model: The study case is a cubic unit cell model consisting of cylindrical fibre ($V_f=0.55$, $E_f=72\text{GPa}$, and $\nu_f=0.22$) and matrix ($E_m=3.3\text{GPa}$, $\nu_m=0.375$) subjected to macroscopic deformation of 0.1% with periodic boundary conditions. Three numerical models have been investigated: 1). Conformal mesh (FEM) with x25 resolution and 2). Voxel-based mesh (FEM & FFT) with x101 resolution.

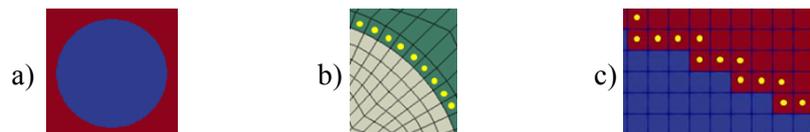


Figure 1: General presentation of the models: a). Unit Cell (Blue: Fibre; Red: Matrix); b). Conformal mesh (Green: Matrix; Grey: Fibre) and c). FFT and FEM Voxel-based mesh (Blue: Fibre; Red: Matrix). (Yellow points: Centroid points of interface zone)

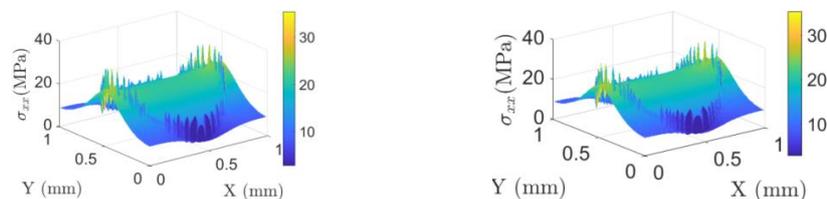


Figure 2: σ_{xx} Stress field (Left: FEM Voxel Mesh; Right: FFT Voxel Mesh)

σ_{xx} stress fields for voxel mesh models: As the direct output results are shown in Figure 2, strong oscillations only occur along with the interface. Which are almost the same between FEM Voxel mesh and FFT considering shape, localisation, and values. These oscillations will affect the accuracy of the final results, which need to be eliminated by introducing the smoothing method.

Smoothing method: In this work, “Neighbour Voxels Average” was implemented based on usage of linear weight function [6]: $WF_i = 1 - L_i / (L_{max} + 1)$, as shown in Figure 3: the **red voxel** is the interface voxel on the matrix side where we want to eliminate oscillations; the **orange voxels** belong to matrix and the **blue voxels** are fibre.

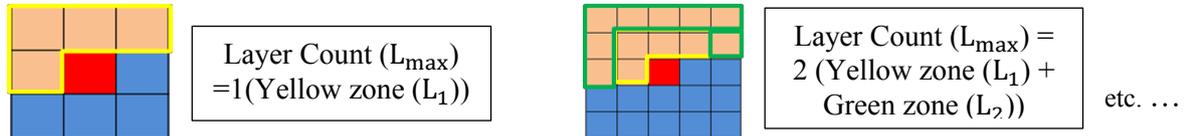


Figure 3: Neighbour Voxels Average method

Quantitative comparison of interface stresses (FEM vs FFT): The comparison of normal σ_{rr} and tangential $\sigma_{r\theta}$ stresses which were obtained from FEM conformal, FEM Voxel-based and FFT model are shown in Figure 4. The difference in numerical values for FEM voxel-based and FFT is less than 0.2%. The differences between FFT and FEM conformal mesh in σ_{rr} , which are also negligible, are mainly due to discretization type.

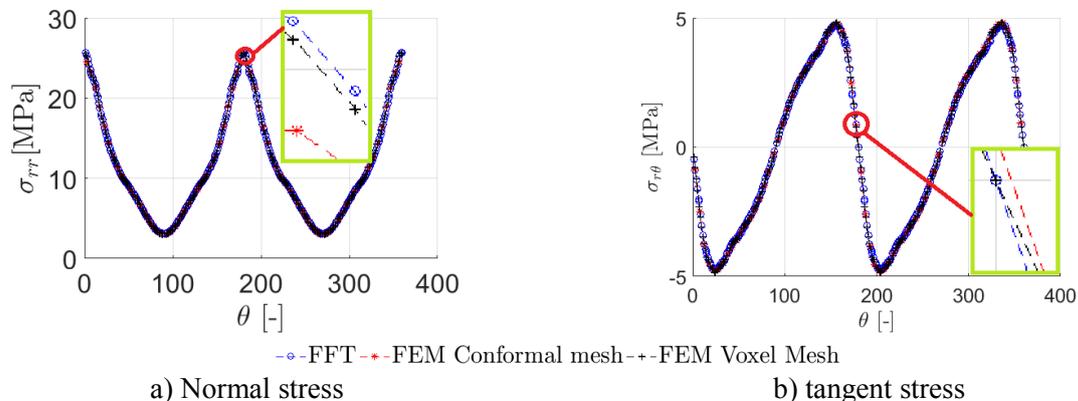


Figure 4: Comparison between FFT and FEM using local smoothing method

Conclusion: It was confirmed that FFT and FEM Voxel based give almost the same results. Moreover, when the local smoothing method is applied FFT gives very close results for the interface stress field as FEM with conformal mesh. Considering that FFT has much more advantages in computation time, FFT is a competitive method in simulating complex multi-scale problems for textile composites.

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