# COMPOSITES WITH PLANAR RANDOM FIBER ARRANGEMENTS

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*Summary* A short fiber reinforced composite material with particular fiber arrangement is investigated by means of a numerical unit cell approach as well as by an analytical mean field type approach. Homogenization and localization is performed for Carbon fiber reinforced Copper with respect to the linear thermoelastic and thermal expansion properties. Simulation results are compared and their applicability is assessed.

## INTRODUCTION

Tailorable materials are desired for high performance applications. The properties of fiber composites can be modified within a wide range by changing the composition and the microgeometry such as fiber length, fiber orientations, etc. Frequently, transversally isotropic material symmetry is required which can be obtained by a fiber orientation distribution of the planar random type. As an example the linear behavior with respect to elasticity, thermal expansion, and thermal conductivity is investigated.

## MICROMECHANICAL APPROACHES

### Numerical Method — Periodic Microfield Approach

Short fibers of aspect ratio 10 are modeled in a planar random type orientation arrangement. A minimum distance between neighboring fibers is maintained in all cases. Agglomerations of parallel fibers within clusters are excluded. Two different unit cells with some fifty fibers and a fiber content slightly higher than 20%vol are generated [1]. Starting from a dilute fiber arrangement, compaction to the final topology is modeled by *PALMYRA (Materials Simulations GmbH, Zürich, Switzerland)*. The final topology is transferred to the finite element program *ANSYS (ANSYS Inc., Canonsburg, PA)*, meshed (Fig. 1), and solved. Homogenization is done by standard approaches giving rise to the overall properties. Localization is performed in terms of field variables within individual fibers by means of statistics [2].

### Analytical Method — Mori–Tanaka Type Mean Field Approach

The analytical simulations are based on a multi-inclusion Mori–Tanaka formulation [3]. The orientation distributions are given both by smooth continuous probability functions and by discrete orientations corresponding to those in the unit cells. The fibers are modeled as spheroids (typical for standard methods) and as cylinders. For the latter a numerical evaluation of averaged concentrations tensors is performed. Localization is based on averaged fields within individual fibers.

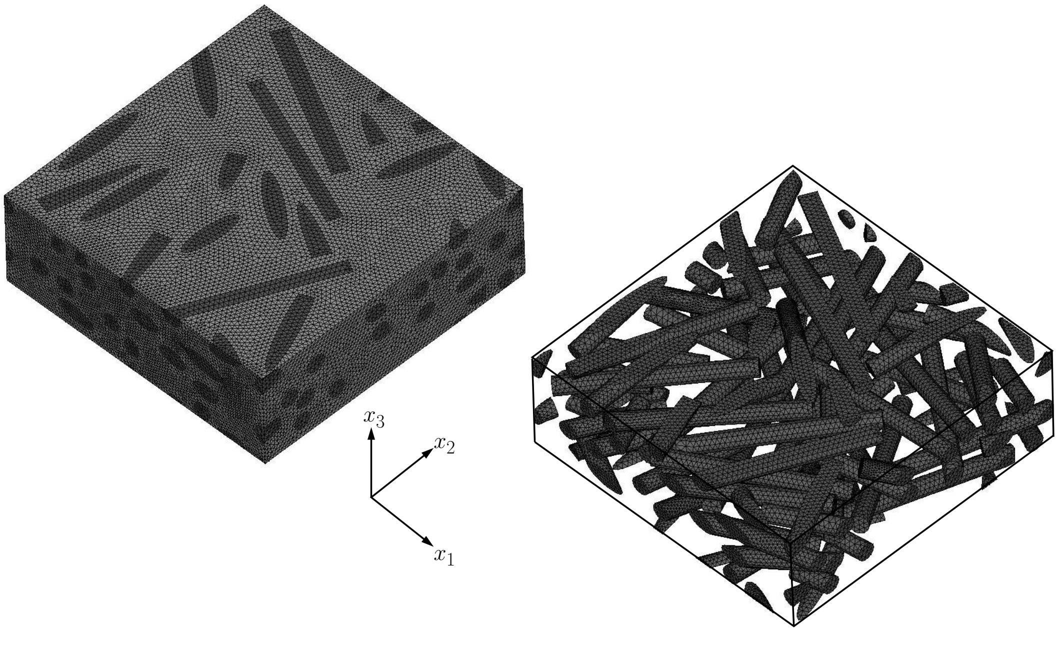

Figure 1: Finite element model of one unit cell; fibers and matrix (left) and fibers only (right).

Table 1: Material data for isotropic Copper matrix and transversally isotropic Carbon fibers.

| | $E_1$ [GPa] | $E_2 = E_3$ [GPa] | $\nu_{12} = \nu_{13}$ | $G_{12} = G_{13}$ [GPa] | $G_{23}$ [GPa] | $\alpha_{11}$ [$10^{-6}$/K] | $\alpha_{22} = \alpha_{33}$ [$10^{-6}$/K] | $K_{11}$ [W/mK] | $K_{22} = K_{33}$ [W/mK] |
|---|---|---|---|---|---|---|---|---|---|
| Cu | 125 | 125 | 0.35 | 46.3 | 46.3 | 16 | 16 | 360 | 360 |
| C | 220 | 15 | 0.2 | 10 | 5 | −0.5 | 10 | 1000 | 100 |

## EXAMPLE AND RESULTS

As example Copper reinforced by Carbon short fibers is investigated. Material data is given in Table 1. A perfect interface is assumed throughout the present work; detailed studies on the effect of imperfect thermal interfaces are given in [1,4].

### Homogenization

Both methods allow for the prediction of the complete set of overall material parameters, i.e. the extraction of the entire tensors. The predicted overall thermal conductivity, $\boldsymbol{k}$, the overall coefficient of thermal expansion, $\boldsymbol{\alpha}$, and the overall elasticity tensor, $\boldsymbol{E}$, are given for one unit cell.

$$\boldsymbol{k} = \begin{pmatrix} 378.9 & 0.2 & -1.4 \\ 0.2 & 370.8 & 1.4 \\ -1.4 & 1.4 & 289.8 \end{pmatrix} \quad [\mathrm{W/mK}] \qquad \boldsymbol{\alpha} = \begin{pmatrix} 13.8 & -0.08 & -.16 \\ -0.08 & 13.8 & 0.10 \\ -.16 & 0.10 & 17.3 \end{pmatrix} \quad [10^{-6}/\mathrm{K}]$$

$$\boldsymbol{E} = \begin{pmatrix} 140.97 & 64.22 & 60.00 & -0.38 & 0.12 & -0.37 \\ 64.23 & 145.69 & 60.73 & 0.53 & 0.12 & 0.19 \\ 59.99 & 60.71 & 123.14 & -0.02 & 0.02 & -0.21 \\ -0.38 & 0.53 & -0.02 & 40.56 & -0.40 & 0.21 \\ 0.12 & 0.12 & 0.02 & -0.40 & 33.23 & 0.07 \\ -0.37 & 0.19 & -0.21 & 0.21 & 0.07 & 33.51 \end{pmatrix} \quad [\mathrm{GPa}]$$

The variation of the predicted properties from the second cell is less than 2%. The tensor elements by the Mori–Tanaka computations differ from the unit cell predictions by a few percent only. Results based on the probability funcitons are transversally isotropic.

### Localization

Localization is performed by both approaches. Here, as example, the fields in individual fibers as response to an overall temperature rise of 1K are given. The maximum principal stresses evaluated from both unit cells is of Gaussian type distribution with a minimum of 2.39 and a maximum of 2.93MPa. The analytical approach yields 3.14–3.21MPa and 3.00–3.06MPa for spheroidal and cylindrical fibers, respectively.

## CONCLUSIONS

The unit cells are sufficiently large for practical predictions of the composite's behavior, which is indicated by the overall tensors as being nearly transversally isotropic. The analytical approach is shown to be sufficiently accurate for homogenization as well as localization for the studied material system and properties.

### References

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