Thermal Conduction In Anisotropic Granular Mixtures

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Abstract

With the ongoing electrification of vehicles as well as rapid digitalization, thermal management is on everyone´s lips. This includes the use of ever-better materials, specifically tailored regarding their thermal properties. To fine-tune the thermal conductivity of a material, composite materials with specified volume contents can be used. However, many additives and materials used to improve thermal conductivity exhibit a certain degree of anisotropy. This anisotropy leads to unexpected and counterintuitive effects that need to be accounted for prior when designing specific composite materials. That goes at the cost of tailored thermal conductivity. Here, we combine two approaches: composite materials with a certain amount of thermally anisotropic constituents allow us to maintain thermal anisotropy as well as the ability to adjust the resulting thermal conductivity to specific applications.

With our numerical studies, we show that introducing thermal anisotropic components in granular arrangements drastically changes the way of heat transfer inside the material. Specifically, our geometry in the 2D case represents a hexagonal array of particles. To account for the contact between the particles, e.g., in pressed materials, straight lines are used as depicted in Figure 1. A newly developed Java® method in the Application Builder is used to assign the material properties of interest to the granules (isotropic and anisotropic with certain orientations). The code allows for either random distribution of material properties or clustering for given area fractions. The studies are automatically calculated followed by a subsequent evaluation of the normal total heat flux evaluation of the normal total heat flux. The obtained results are automatically compiled in ASCII files that allow for a detailed analysis of the effective thermal conductivities based on Python®. The use of the COMSOL® Application Builder allows us to automatize the creation of a huge amount of binary composite structures with different amounts and orientations of anisotropic constituents.

The prediction of the COMSOL® simulations was confirmed by infrared thermography on small model structures made of thermally anisotropic laminates. Such laminates are sheets of carbon fibers in a polymer resin matrix that show a high preferential thermal conductivity along one direction (7 Wm-1K-1 vs. 0.5 Wm-1K-1). These sheets can be cut to custom sizes and arranged according to the simulated structures.

Our findings reveal that the prediction of the thermal conductivity of anisotropic composites is not possible based on classic percolation theory, which only holds for the case of composites with isotropic constituents. Most interestingly, the use of anisotropy enables us to even better control the effective thermal conductivity depending on the number and orientation of anisotropic constituents in the composite. We want to stress further that anisotropy does not only affect the macroscopic thermal properties. The temperature distribution inside such anisotropic composite materials gives rise to sharp local temperature gradients. Consequently, the conscious use of thermal anisotropy in composite structures can be a great enhancement of tailoring materials for thermal management.

Figures used in the abstract

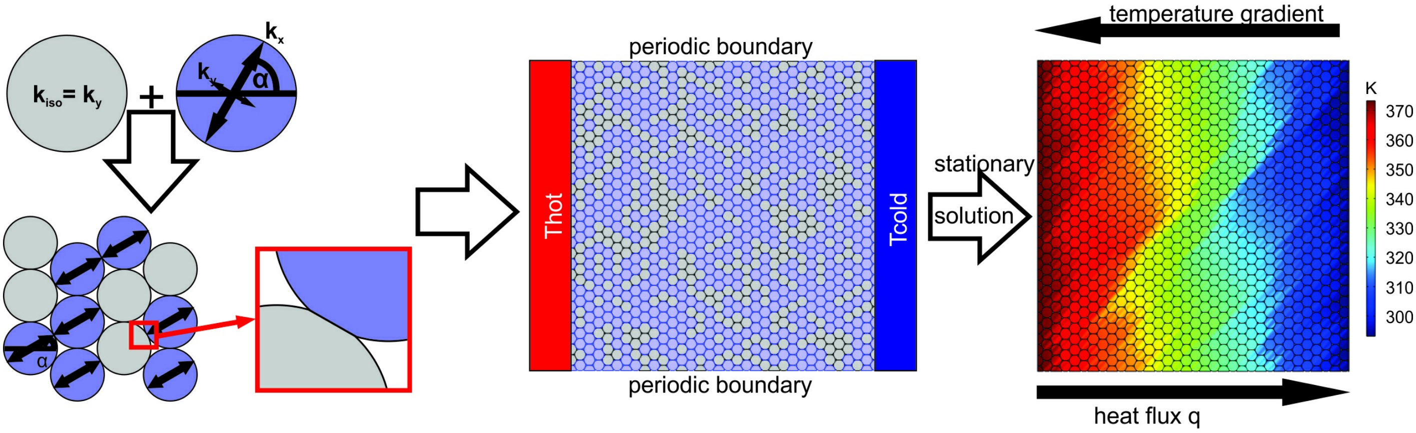

Figure 1 : Schematic of a 2D hexagonal lattice of granules composed of isotropic (grey) and thermally anisotropic (blue) granules with a fixed orientation a. An exemplarily calculated temperature distribution with 60 % anisotropic granules is shown on the right.

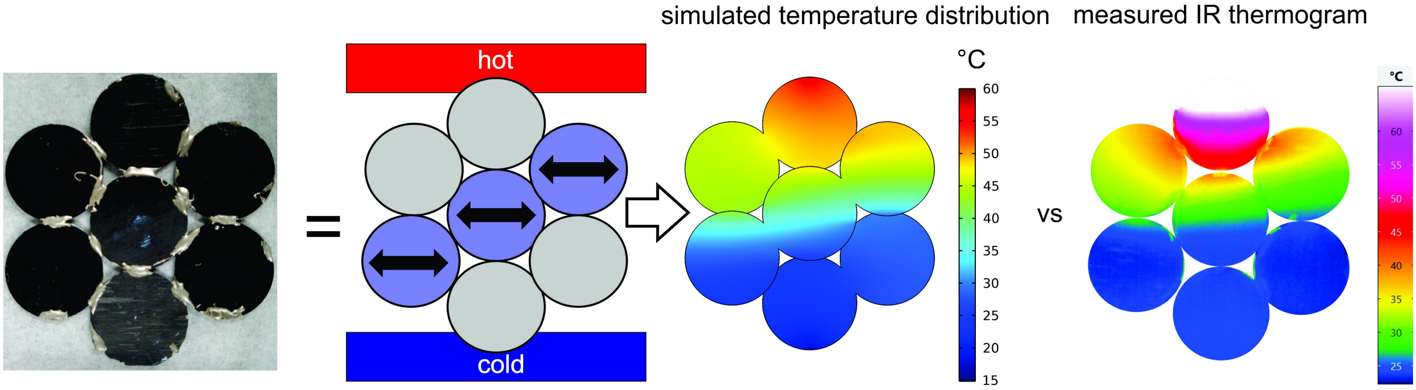

Figure 2 : Verification of the simulations using thermal infrared measurements of the temperature distribution of thermally anisotropic carbon fiber laminates.