PRECISE 3D STRUCTURING OF POLYMER NANOCOMPOSITES USING TRIAXIAL MAGNETIC FIELDS

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Polymer nanocomposites have been sought after for their light weight, high performance (strength-to-mass ratio, renewability, etc.), and multi-functionality (actuation, sensing, protection against lightning strikes, etc.). Nano-/micro-engineering has achieved such advanced properties by controlling crystallinity, phases, and interfaces/interphases; hierarchical structuring, often bio-inspired, has been also implemented. While driven by the advanced properties of nanofillers, properties of polymer nanocomposites are critically affected by their structuring and interfaces/interphases due to their small size (< ~50 nm) and large surface area per volume. Measures of their property improvement by nanofiller addition are often smaller than theoretically predicted. Currently, application of these novel engineered materials is limited because these materials cannot often be made in large sizes without compromising nano-scale organization, and because their multi-scale structure-property relationships are not well understood.

In this work, we study precise and fast nanofiller structuring with non-contact and energy-efficient application of oscillating magnetic fields. Magnetic assembly is a promising, scalable method to deliver bulk amount of nanocomposites while maintaining organized nanofiller structure throughout the composite volume. In the past, we have demonstrated controlled alignment of nanofillers with tunable inter-assembly distances with application of oscillating one-dimentional magnetic fields (~100s of G), by taking advantage of both magnetic attraction and repulsion. The low oscillation frequency (< 1 Hz) was tuned to achieve maghemite nanofiller alignment patterns, in an epoxy matrix, with different amount of inter-nanofiller contacts with the same nanofiller volume fraction (see **Figure 1a**). This work was recently expanded to three-dimensional assembly using a triaxial Helmholtz coil system (see **Figure 1b**); the system can apply the triaxial magnetic fields of varying magnitude (max. ±300G, ±250G, ±180G (x-y-z)) and frequency (0 to 1 Hz, ~0.1 Hz resolution) with controlled phase delay to the sample size of 1.5” x 2.5” x 3.5”(x-y-z). Two model systems are currently studied: maghemite nanofillers in an elastomer for magnetoactuation, and nickel-coated CNTs in an thermoset for mehcniacl and transport property reinforcement. The assembled nanofiller structures are currently characterized by microCT; microCT scan data (see **Figure 1b**) are segmented through a machine learning algorithm, and will be modeled for their transport properties using a Monte Carlo method. These estimated properties will be compared with the experimentally characterized mechanical, transport, and actuation properties, providing the structure-interphase-property relationships. In future, we plan to integrate these nanocomposites to CFRPs for interlaminar property reinforcement, possibly with an out-of-autoclave composite processing.

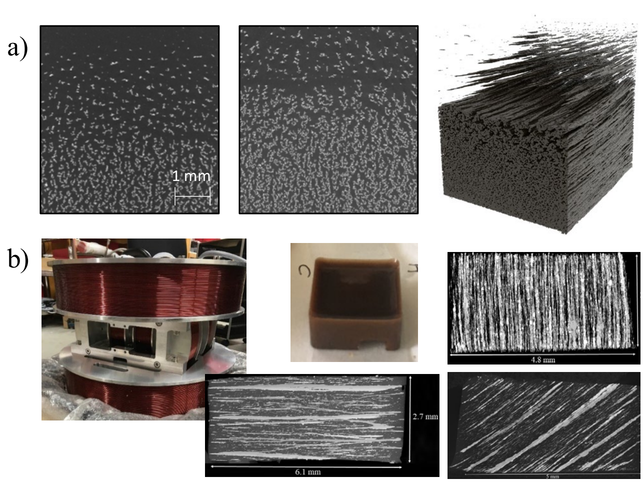

Figure 1. Magnetic tailoring of polymer nanocomposites and their microCT scans.

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