Secondary Phase Aware Reduced Order Modeling of Permanent Magnet Hysteresis

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The performance of sintered NdFeB magnets is commonly assessed by the coercive field, which is governed by the magnetization reversal of large ensembles of micrometer-scale grains. Modeling and simulation provide an efficient means to explore the influence of, for example, nanostructural features and chemical composition. However, conventional micromagnetics is typically limited to sample volumes on the order of $1\,\mu m^3$, preventing studies of microstructural effects in sintered magnets whose grain sizes extend over many micrometers.

Here we present a reduced-order model (ROM) that enables efficient hysteresis simulations of large multigrain systems with realistic grain sizes reaching the micrometer regime[1]. The approach exploits two characteristic features of hard-magnetic reversal: (i) grains typically switch in an effectively single step, and (ii) nucleation preferentially initiates near the grain surface. Accordingly, each grain is represented by a single magnetic moment, while the switching event is determined analytically by evaluating the effective field along the grain surface and comparing it with a locally defined switching criterion.

We investigate NdFeB alloys with partial substitution of Nd by Ce. To capture microstructural degradation effects, we extend the ROM to account for secondary phases (e.g., oxides) by locally scaling the required switching field according to the spatially varying phase content[2]. We validate the extended model using experimental data acquired in a high-throughput fashion from a compositionally graded Nd/Ce hard-magnetic film with varying oxide content. While quantitative deviations remain, the simulated coercive fields reproduce the experimentally observed trends and show a robust correlation with the measured coercivity landscape. These results demonstrate that the ROM provides a practical route to link composition and microstructure to coercivity in technologically relevant, large-grain hard magnetic materials.

References:

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