Grain size dependent FORC investigations on rare earth based permanent magnets.

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First-order-reversal-curve (FORC) diagrams yield a great variety of magnetic information such as coercive and interaction field distributions. We have recently shown that FORC diagrams can provide detailed information, as being just a magnetic fingerprint [1,2,3]. Muralidhar *et al.* demonstrated that FORC on MnBi can provide deep insight in the relationship between magnetism and microstructural properties, as grain size distributions and grain shapes. Hence, a more detailed understanding of micromagnetic mechanisms in hard magnets has been provided. Following these studies we investigated bulk rare earth based permanent magnets, namely commercial NdFeB and SmCo, and their FORC density relationship to microstructural properties.
We systematically manipulated the microstructure of the samples by consecutive annealing (at different temperatures and intervals), and correlated their grain size distributions with FORC diagrams. All magnetic measurements as well as the annealing cycles were performed using a Quantum Design MPMS 3 VSM SQUID magnetometer. Microstructural information were obtained by SEM and Kerr microscope images.
Our analysis of the grain size distributions showed that the grain sizes shift to higher diameters and the distribution broadens for longer annealing times, as expected due to Ostwald ripening of the grains. The room temperature FORC diagrams revealed that the coercive field distribution of the hard magnetic component of the samples moves to slightly lower coercive field for longer annealing durations and the width of this field distribution increases (see Fig. 1). Furthermore, we analyzed the interaction field distributions and compared intensity ratios of the FORC peaks for different samples. The results are in agreement with micromagnetic theory which states a dependence of the coercive field on the grain size, more precisely a decreasing of coercivity with increasing diameters [4].
Our results demonstrate the versatility of FORC investigations providing rich additional information, beyond magnetic fingerprints, enabling detailed understanding of coercive and interaction field distributions of our samples related to microstructure and grain size distributions.

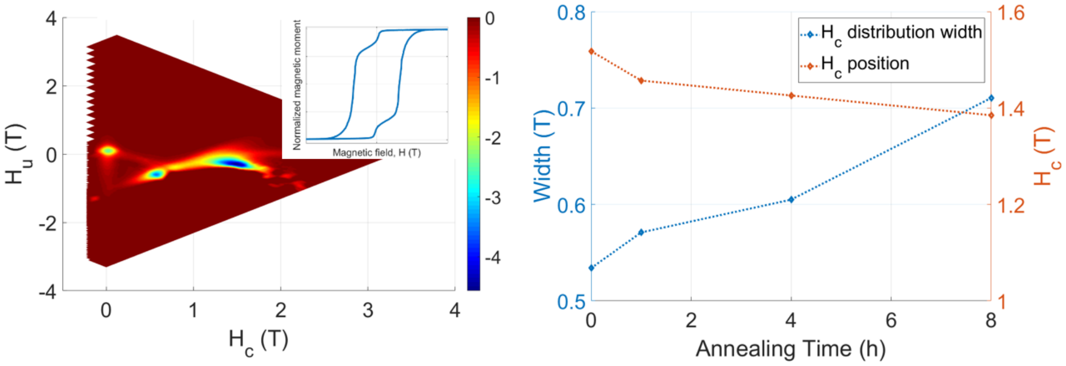

Figure 1. Left: FORC diagram of NdFeB and corresponding full hysteresis showing a soft and hard magnetic component (inset). Right: Width and Position of the hard magnetic coercive field distribution as function of annealing time.

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[4] D. Goll, Handbook of Magnetism and Advanced Magnetic Materials (2007).