Poster | Raw materials

Tue. Jul 29, 2025 4:35 PM - 6:00 PM JST | Tue. Jul 29, 2025 7:35 AM - 9:00 AM UTC Green zone, Conference rooms 101 and 102(1F)

[P2] Raw Materials & Recycling

Session Chair: Mr. Johann Fischbacher (University for Continuing Education Krems, Austria), Dr. Yusuke Hirayama (AIST, Japan)

[P2-33] Hydrogen-based functional recycling of Nd-Fe-B sintered magnets from e-mobility and wind power: influence on GBDP microstructure evolution and possibilities to improve the resulting properties

*Mario Schönfeldt[1,2], Jürgen Rossa[1], Konrad Opelt[1,2], Kilian Schäfer[2], Lukas Schäfer[2], Fernando Maccari[2], Matic Jovičević-Klug[3], Tim M. Schwarz[3], Chi-Chia Lin[1,2], Mahmudul Hasan[1], Jürgen Gassmann[1], Dierk Raabe[3], Oliver Gutfleisch[2] (1. Fraunhofer IWKS, Fraunhofer Research Institution for Materials Recycling and Resource Strategies, Aschaffenburger Str. 121, 63457 Hanau (Germany), 2. TU Darmstadt, Department of Materials and Geosciences, Functional Materials, Peter-Grünberg-Str. 16, 64287 Darmstadt (Germany), 3. Max-Planck-Institute for Sustainable Materials GmbH, Department of Microstructure Physics and Alloy Design, Max-Planck-Str. 1, 40237 Düsseldorf (Germany))

Keywords：recycling、Nd-Fe-B、sustainability、permanent magnets、grain boundary diffusion process

---

A sustainable energy and mobility transition is essential for reducing CO_2 emissions and combating climate change. The global rollout of electromobility and industry electrification is expected to account for the largest share of the increasing demand for high performance Nd-Fe-B magnets. More specific, 95 % of all electric vehicle traction motors worldwide make use of rare earth (RE) magnets, a massive trend that will increase the required quantity of RE magnets in this sector. The high operating temperatures of up to 180 °C require heavy rare earth elements (HREs) such as Dy or Tb to increase the materials' temperature resistance. Due to the high criticality and cost of HREs, the magnets used in traction motors have been produced using the grain boundary diffusion process (GBDP) for a number of years. However, the influence of recycling of GBDP scrap magnets and the resulting properties has hardly been investigated to date.

In this work, sintered Nd-Fe-B magnets industrially produced employing the GBDP were recycled by the so-called functional recycling approach, based on hydrogen decrepitation (HD). Recycling of GBDP scrap magnets leads to materials that show a similar decrease in remanence (ΔB_r = -5 %) compared to the recycled products made of conventionally manufactured magnets. In the case of coercivity, however, a significantly larger decrease (ΔH_{cJ} = -21 %) is observed. The dissolution of the special GBDP core-shell microstructure through the different heat treatment steps, including HD, sintering, and annealing was investigated by microstructural and chemical characterization from the mesoscale down to near-atomic scale to understand the substantial loss in coercivity. Nevertheless, the recycled magnets show similar rectangular demagnetization curves at a hysteresis squareness of 96 %, a remanence of 1.31 T, and coercivity of 1703 kA/m. With a renewed GBDP, using 1.5 wt.% Tb, the formation of a core-shell structure with 0.5 µm thick Tbshells - similar to the microstructure of the original magnets prior to recycling - is observed. The coercivity of the recycled magnets is increased by 35 % and shows similar magnetic values as the original industrial magnets at 150 °C and 200 °C, respectively. The temperature coefficients α and β can also be fully restored and even exceed the original values which thus reflects an even improved temperature stability of the recycled magnets compared to the scrap magnets.

Based on these previous results, the particle size distribution of a recycled powder was modified in order to mitigate the deterioration of the magnetic properties due to contaminations in the recycled powder. For this purpose, 15 kg of End-of-Life (EoL)-magnets from wind turbines were decrepitated under hydrogen and subjected to inline classifying after jet-milling to remove small particles (< 1 µm) to reduce the oxygen content in the powder. The particle size distribution, specific surface area, chemical composition, impurity content, microstructure, and magnetic properties were analyzed in detail. The classifying leads to a narrower particle size distribution and an improved D_{90}/D_{10} ratio of 3.00 compared to 4.20 before classifying, and an increase in the D_{50} value from 5.78 µm to 6.20 µm. With the use of the classified powder, the oxygen content of the recycled magnet could be successfully reduced from 0.33 wt.% to 0.18 wt.%. In the case of nitrogen and carbon, even the values of the EoL-magnet are achieved or undercut. The magnetic properties of the classified recycled magnet (B_r = 1.29 T) outperform the EoL-magnet properties (B_r = 1.27 T) and high squareness of 98 % is reached.

The use of recycled Nd-Fe-B magnets offers several advantages and has the potential to make a wide range of products more sustainable, to save CO_2 and reduce harmful environmental impacts and making supply chains and the supply of critical REs more resilient.

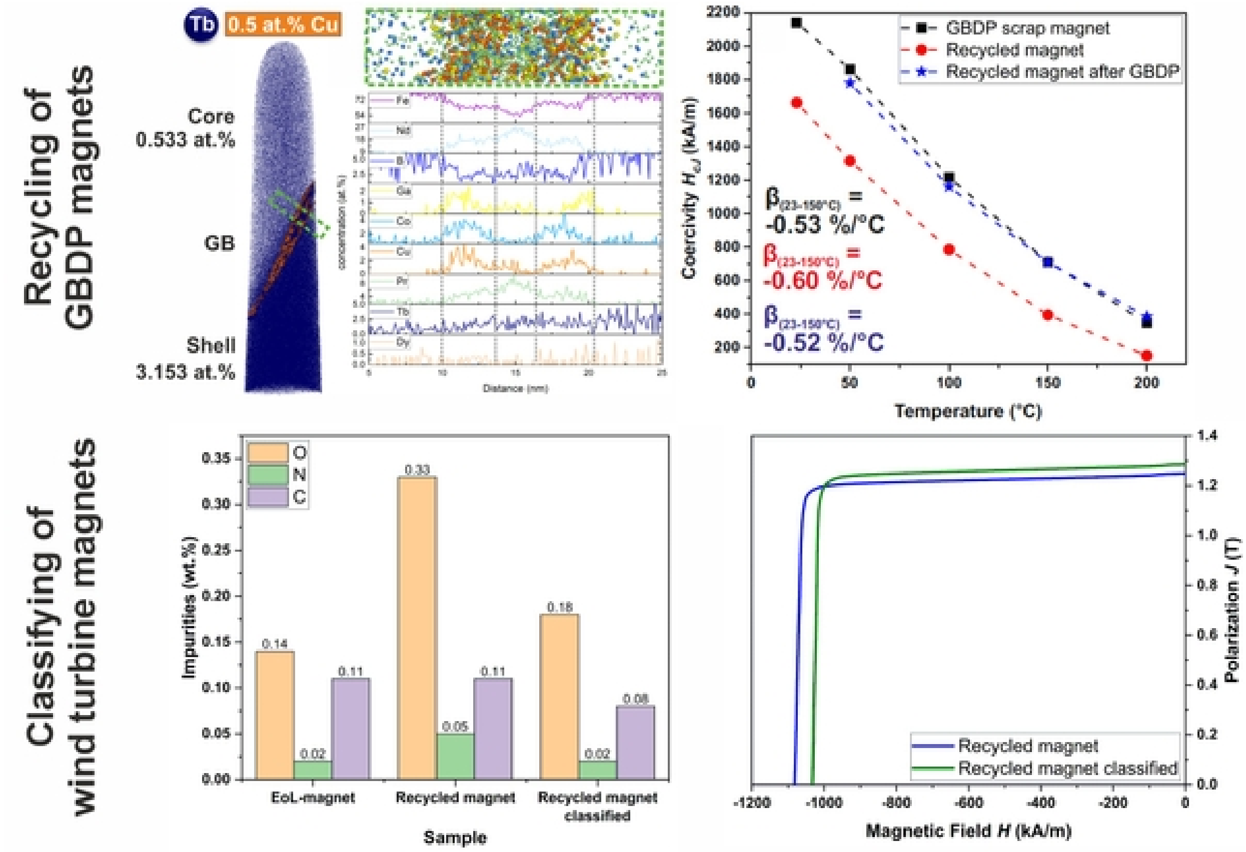

Figure 1: Recycling GBDP magnets poses challenges in terms of their microstructure, but the magnetic properties can be restored (top); classifying can improve the content of impurities and the magnetic properties of recycled magnets (bottom).