Microstructural and Chemical Evolution of Recycled HDD-Derived NdFeB Magnets During Rapid Solidification Processing

Irena Gejdoš Janotová [a], Jana Boržíková, Peter Švec Sr.[b], and Dušan Janičkovič

Institute of Physics, Slovak Academy of Sciences, Dúbravská cesta 9, 845 11 Bratislava, Slovakia

[a] Corresponding author: irena.janotova@savba.sk
[b] Peter.Svec@savba.sk

Abstract. Increasing demand for Nd-Fe-B permanent magnets in electric mobility, renewable energy technologies and advanced electronic devices has intensified interest in sustainable recycling routes for rare-earth magnetic materials. End-of-life hard disk drives (HDDs) represent a valuable secondary source of NdFeB magnets; however, maintaining chemical purity, phase stability and microstructural homogeneity during recycling remains a significant challenge due to the high affinity of rare-earth elements for oxygen and to the presence of protective surface coatings. In this work NdFeB magnets recovered from end-of-life HDDs produced by different manufacturers were investigated as feedstock for recycling and reprocessing into rapidly solidified precursor materials. The recycling route comprised demagnetization, mechanical and chemical removal of Ni-based protective coatings, hydrogen-assisted treatment, controlled-atmosphere melting, master alloy preparation and subsequent rapid solidification by planar flow casting (PFC). Particular attention was devoted to the evolution of chemical composition, impurity content, oxide formation and microstructure throughout the individual processing steps. Chemical composition and elemental distribution were evaluated using inductively coupled plasma optical emission spectroscopy (ICP-OES) and X-ray fluorescence analysis (XRF) while microstructural development and surface quality were investigated by digital optical microscopy. Phase content and structural stability were assessed using X-ray diffraction analysis. The results revealed measurable differences in the chemical composition of magnets originating from different HDD manufacturers, reflecting variations in the original alloy design and rare-earth content. The efficiency of coating removal and melting procedures was evaluated with respect to contamination control and oxide formation. Structural analyses confirmed the preservation of the tetragonal $Nd_2Fe_{14}B$ hard magnetic phase after remelting, while rapid solidification promoted the formation of a refined and chemically homogeneous microstructure with reduced segregation compared to conventionally solidified materials. The resulting melt-spun ribbons exhibited morphological characteristics suitable for subsequent comminution and powder-based permanent magnet manufacturing routes. The presented study provides insight into the relationship between recycling-induced chemical and microstructural changes and quality of rapidly solidified NdFeB precursor materials. The obtained results contribute to the development of robust recycling technologies for rare-earth permanent magnets and support the establishment of sustainable circular value chains for critical raw materials in Europe.

Acknowledgement. This work was supported by the project “Sustainable Innovation Investment Catapult for Permanent Magnets” (Project 101160837 - SICAPERMA - I3-2023-INV2a) which aims to establish an integrated European value chain for recycled permanent magnets by connecting dismantling, recycling, material reprocessing and industrial deployment of Nd-Fe-B magnetic materials.