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Review

Neodymium as the main feature of permanent magnets from hard disk drives (HDDs)

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ABSTRACT

As a way to manage neodymium–iron–boron (NdFeB) magnets wasted in end-of-life hard disk drives (HDDs), a waste characterization is needed prior to a recycling process. Due to their magnetic properties, NdFeB magnets are essential in technological applications nowadays, thus causing an increase in the industrial demand for rare earth metals. However, these metals have a short supply, since they are difficult to obtain from ores, creating a critical market. In this work, a study of the characterization of sintered neodymium–iron–boron magnets was undertaken by qualitatively and quantitatively uncovering the neodymium recovery potential from this type of electronic waste. From the collection and disassembly of hard disk drives, in which the magnet represents less than 3% of the total weight, an efficient demagnetization process was proceeded at 320 °C. Then, the magnet was ground and screened for an X-ray diffraction (XRD) analysis, which showed the $Nd_2Fe_{14}B$ tetragonal phase as the dominant constituent of the sample. An analysis was also carried out in a scanning electron microscope (SEM) and an inductively coupled plasma optical emission spectrometer (ICP-OES), where the magnet composition showed 21.5 wt% of neodymium and 65.1 wt% of iron, among other chemicals. This Nd content is higher than the one found in Nd ores, enhancing the recyclability and the importance of waste management.

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1. Introduction

Reports from China (Yang et al., 2008), India (Dwivedy and Mittal, 2010), and Brazil (ABINEE, 2016) show a decreasing lifetime tendency for computers over the years. World data indicate that in 2011, 372 million computers were sold worldwide and sales were projected to hit 517 million units by 2015, and since there is no exact number for discarded equipment, studies predict that this number may be assumed to be proportional to the quantity of computers in use worldwide (Veit and Bernardes, 2015).

Computers, and consequently their HDDs, which contain some rare earth elements (REE), become a great source of critical metals

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when reaching end of life; however, reported recycling rates show poor reuse of metals, which is typically less than 1% for REEs. With the Waste Electrical and Electronic Equipment (WEEE) Directive being established in 2002, it is presumed that many of the waste products containing these valuable metals were disposed in landfills prior to this date (Gutiérrez-Gutiérrez et al., 2015).

It is reported that HDDs are the largest users of NdFeB magnets in electronic products, with about 674 million units manufactured until 2009 (Zepf, 2013). Neodymium–iron–boron magnets are the strongest permanent magnets commercially available today, and they constitute a key component of the transition toward a low-carbon energy economy applied, for example, in direct drive wind turbines, electric and hybrid vehicles, hard disk drives, and cell phones (Rollat et al., 2016).

NdFeB magnets were developed in the 1980s, becoming the third generation of permanent magnets (Pan, 2013), which are made typically by a primary phase of $Nd_2Fe_{14}B$ tetragonal structure, one phase of small volume fraction that is rich in boron, $NdFe_4B_4$, and an Nd-rich phase (Fu et al., 2013). The superior magnetic properties of this magnet are the main reasons for its applicability, as it is reported the saturation magnetization of approximately 16 kG and maximum magnetic product of 40–50 MGOe. However, NdFeB magnets are not resistant to high temperatures, since their Curie temperature stands around 312 °C, the lowest among permanent magnets (Herbst and Croat, 1991), as well as corrosion; therefore, they are coated with protective layers.

Besides iron (Fe), neodymium (Nd), and boron (B), these magnets contain praseodymium (Pr), dysprosium (Dy), and traces of some transition metals. The presence of cobalt (Co) and Dy in the sintered magnets helps to increase the Curie temperature and improves the temperature stability (Zakotnik et al., 2016). Also, the addition of dysprosium and terbium (Tb) is effective to enhance coercivity, because they increase the magnetic anisotropy field of the (Nd, Dy, Tb)FeB compound. However, this results in a considerable reduction in a remanence (Hirota et al., 2006). Several authors have published concentrations of these metals found in magnets; thus, Table 1 presents an average.

The use of neodymium, praseodymium, dysprosium, and other rare earth elements (REE) has generated economic and political crises due to insufficient availability. Because China produces more than 90% of all the rare earths (Binnemans et al., 2013), some countries are gradually losing the capacity of mining and processing the rare earth ores, and hence manufacturing rare earth products. A gap in the supply chain has been created due to diminished manufacturing infrastructure and has caused a fluctuation in prices (Du and Graedel, 2013). On top of that, the extraction of REE from ores involves toxic mineral acids and can lead to accumulation of radioactive tailings because deposits also contain radioisotopes of thorium and uranium (Zakotnik and Tudor, 2015).

Studies show that until 2025, HDDs will remain as the largest source of recycled neodymium, since, technically, recycling it is relatively easy, because magnets are always found in the same place, and they are often easily removable once the HDD is opened. The same study asserts that since HDDs have been in production for decades and the amount of magnet per HDD has not decreased significantly in the recent past, the HDDs are the only significant and consistent source of recyclable NdFeB at this moment (Sprecher et al., 2014). In 2007, the global in-use stocks of the REE Nd, Pr, Dy, and Tb in NdFeB magnets in computers, audio systems, wind turbines, automobiles, household appliances, and MRI were estimated to be 97,000 tons, four times the extraction level in that year (Rademaker et al., 2013).

Some previous studies also focused on characterizing the NdFeB magnets regarding the crystal structure. The characterization of sintered magnets was investigated by X-ray diffraction (XRD) and has proved the existence of the tetragonal $Nd_2Fe_{14}B$ phase (Ali et al., 2009; Deng et al., 2015; Miura et al., 2008). Regarding the microstructure, the existence of grains between 1 and 11 μm was verified and the determination of the neodymium-rich phase and the matrix phase $Nd_2Fe_{14}B$ was undertaken (Fu et al., 2013; Miura et al., 2006; Zakotnik et al., 2009). A study also showed that milling and screening concentrates Nd on smaller size fractions (Sun et al., 2015).

End-of-life products in waste streams may be reused and/or recycled, or else eliminated in the "Landfill and Environment" process, becoming a part of the "Waste management" process (Rollat et al., 2016). So, due to the very limited literature on this type of waste, it is extremely important to develop research that can identify the phases, composition, and mainly the amounts of components, therefore establishing an efficient route of recycling wastes, which is the objective of this article. The major technical, economic, and environmental problems on extracting rare earth metals from their ores justify studies on managing this waste, especially for the content of rare earths that NdFeB magnets hold.

2. Materials and methods

Fig. 1 shows the schematic diagram of the experimental procedure used in this article. The end-of-life HDDs of desktops and laptops were collected in Porto Alegre city. At first, the HDDs were manually dismantled and the sintered magnets as a whole were isolated and proceeded to thermal demagnetization in a high-temperature furnace up to 320 °C for 260 min. After demagnetization, the first qualitative characterization was conducted on a scanning electron microscope (SEM) (PHENOM Pro-X), randomly taking

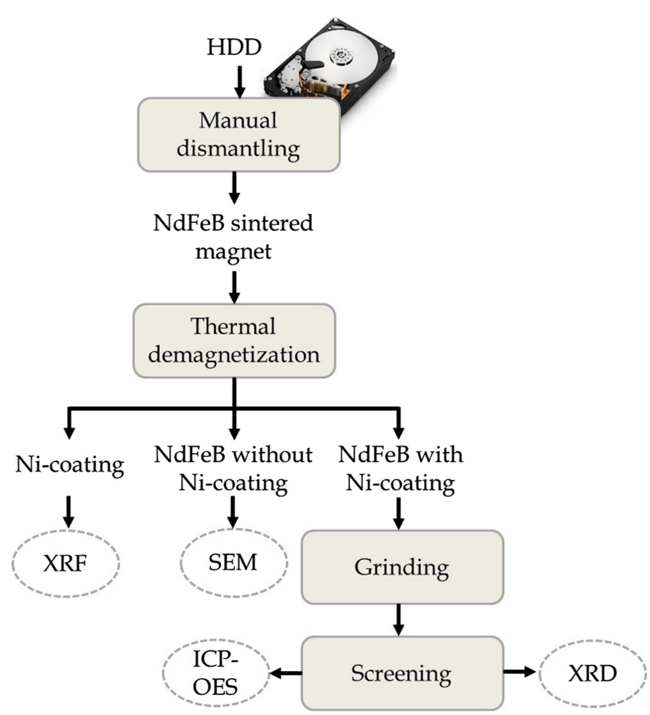

Fig. 1. Schematic diagram of the experimental procedure.

Table 1
Average composition of magnets in wt%.

Element	Nd	Pr	Dy	Fe	B	Co
Average	25.3	3.83	2.66	64.56	0.97	2.42

(Stuhlpfarrer et al., 2015) adapted.