



**International
Standard**

ISO 24544

**Rare earth — Recyclable
Neodymium iron boron (NdFeB)
resources — Classification, general
requirements and acceptance
conditions**

*Terres rares — Ressources en néodyme-fer-bore (NdFeB)
recyclable — Classification, exigences générales et conditions de
recette*

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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This document was prepared by Technical Committee ISO/TC 298, *Rare earth*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Rare earth elements (REEs) are an important ingredient in products such as magnets, luminous devices and catalysts. Among these, magnets, especially neodymium iron boron ($\text{Nd}_2\text{Fe}_{14}\text{B}$ or NdFeB in shortened form), consume more than a mass fraction of 30 % of rare earths. The process of exploring and producing rare earths is causing pressure on the environment due to the use of different kinds of chemical agents as well as the resulting emissions of waste water, slag, dust and gas. In addition, there are limited primary rare earth resources available for economically viable production across the world. The recovery of rare earth from industrial products (including scraps and sludge) and end-of-life (EOL) products will help address these problems, particularly from a long-term perspective.

The NdFeB magnet is the permanent magnet of choice in many products, including in the motors of electronic vehicles and hard discs in computers, and is a key component of air conditioners. The use of both sintered and bonded NdFeB products has grown steadily during the last several decades at an average annual growth rate of around 9 % and 6,2 %, respectively.^[1] The steady growth of NdFeB production has led to an increase in recyclable resources, especially sintered NdFeB scrap. These recyclable NdFeB resources contain not only about 30 % of REEs, but also other valuable elements such as Co, Ni, Ga, etc., which shows there is significant potential in recycling these resources to effectively supplement rare earth resources.

In addition, when the products containing NdFeB magnets come to the end of their lives, there will be an increase in EOL products. Therefore, recycling rare earth from recyclable NdFeB resources can meet a substantial part of the demand for global light (Nd and Pr) REEs and heavy (Dy and Tb) REEs.

However, a challenge for recycling rare earth is that the recyclable NdFeB resources from different sources and processes can vary significantly in form, shape, chemical composition, phase structure, etc., leading to quite complex and diverse recycling methods. [Figure 1](#) provides an example of sintered NdFeB (S-NdFeB), which accounts for about 90 % of the total market,^[2] to illustrate some of the typical recyclable resources from EOL products and industrial processes, and the recycled products that can be created using a highly efficient and low polluting recovery method as follows:

- For some large sintered NdFeB magnets from EOL products, after removing the coating, the cleaned magnet can be used as raw materials and can be further manufactured into sintered NdFeB magnets.
- NdFeB sludge from industrial products in the machining stage is usually recycled into NdFeB powders or magnets by using a combination of calcium thermal reduction and sintering, or into REE compounds by using hydrometallurgy or thermometallurgy, depending on the oxidation and main phase structure of the sludge.
- Scraps including unqualified bulk, residual powder and other recyclable resources from different processing stages can be applied in different steps of the sintering process and regenerated into recycled NdFeB magnets according to the phase, and the degree of contamination and oxidation.

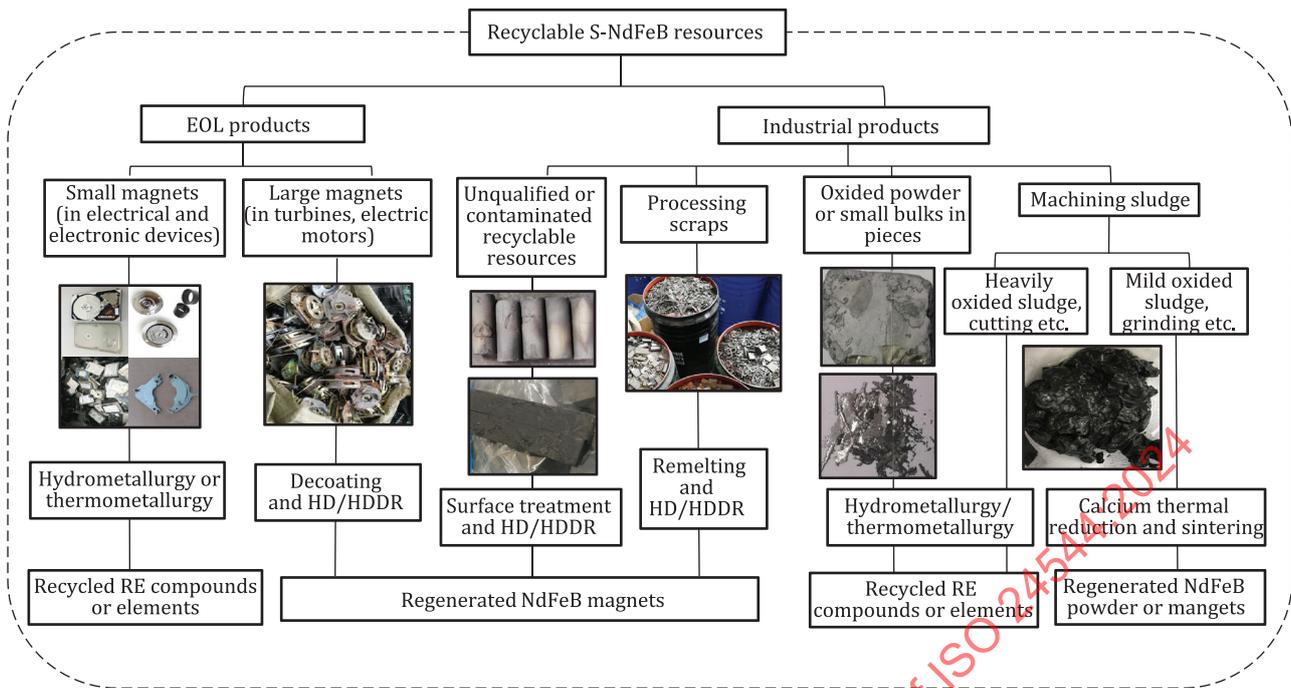


Figure 1 — Typical examples of recyclable NdFeB resources from different sources, and possible methods to recycle to different products

Therefore, it is important to determine the characteristics of different recyclable NdFeB resources. This document provides the classification, general requirements and acceptance conditions for recyclable NdFeB resources, considering the unique characteristics of the different resources and the industrial recycling methods that can be used.

This document promotes the efficient recycling of valuable REE elements across countries that produce and consume magnets.

Rare earth — Recyclable Neodymium iron boron (NdFeB) resources — Classification, general requirements and acceptance conditions

1 Scope

This document specifies the classification, general requirements and acceptance conditions for recyclable neodymium iron boron (NdFeB) resources.

This document is applicable to recyclable NdFeB resources from end-of-life (EOL) products and manufacture processes.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 22450:2020, *Recycling of rare earth elements — Requirements for providing information on industrial waste and end-of-life products*

ISO/TS 22451, *Recycling of rare earth elements — Methods for the measurement of rare earth elements in industrial waste and end-of-life products*

ISO 22453, *Exchange of information on rare earth elements in industrial wastes and end-of-life cycled products*

ISO 22928-1, *Rare earth — Analysis by wavelength dispersive X-ray fluorescence spectrometry (WD-XRFS) — Part 1: Determination of composition of rare earth magnet scraps using standardless XRF commercial packages*

IEC 60404-1, *Magnetic materials — Part 1: Classification*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <https://www.electropedia.org/>

3.1

rare earth element

REE

collective name for scandium (Sc), yttrium (Y) and the lanthanides (La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu), which was approved by the International Union for Pure and Applied Chemistry (IUPAC) in its 2005 Nomenclature of Inorganic Chemistry Recommendations^[1]

Note 1 to entry: Certain terms and corresponding abbreviated terms are common such as rare earth element (REE or RE) and rare earth oxide (REO).

Note 2 to entry: Rare earth elements are frequently referred to as being either light rare earth (LREE), medium rare earth (MREE) or heavy rare earth (HREE), with LREE including the elements between lanthanum (La) and neodymium (Nd), MREE including the elements between samarium (Sm) and gadolinium (Gd), and HREE including the elements from terbium (Tb) to lutetium (Lu) as well as scandium (Sc) and yttrium (Y).

Note 3 to entry: Didymium is commonly used to express a mixture of the elements Pr and Nd.

Note 4 to entry: Characteristics of rare earth elements are described in ISO 22444-1:2020, Annex A.

[SOURCE: ISO 22444-1:2020, 3.1]

3.2

neodymium iron boron

NdFeB

kind of permanent magnet made from an alloy of neodymium, iron, and boron to form the $\text{Nd}_2\text{Fe}_{14}\text{B}$ tetragonal crystalline structure

3.3

sintered neodymium iron boron

S-NdFeB

NdFeB (3.2) magnet prepared by a powder metallurgy method

Note 1 to entry: In the powder metallurgy method, the raw materials are melted and casted into flake-like ingots with strip-casting technique; the ingots are pulverized with hydrogen decrepitation technique and then milled into single-crystal powders with jet-milling technique; the powders are aligned in magnetic field and pressed into green compacts and then sintered into dense blocks; the blocks are heat-treated, cut to shape, surface treated and magnetized.

Note 2 to entry: Sintered NdFeB magnets are the most widely used rare earth magnet and contribute to about 92 % market supply of all NdFeB magnets. They have the strongest energy density of all kinds of permanent magnets.

3.4

bonded neodymium iron boron

B-NdFeB

NdFeB (3.2) magnet prepared by mixing NdFeB powders and binders such as organic or inorganic adhesives, and then compressed or injected into dense blocks, surface treated and magnetized

Note 1 to entry: Bonded NdFeB magnets contribute to 6 % to 7 % of the market supply of all NdFeB magnets. They usually exhibit lower magnetic properties than *S-NdFeB* (3.3) magnets but can be prepared directly into a net shape or near net shape with complex shapes.

3.5

deformed neodymium iron boron

D-NdFeB

NdFeB (3.2) magnet prepared with hot pressing and hot deformation of nanocrystalline NdFeB ribbons

Note 1 to entry: Deformed NdFeB magnets contribute to about 1 % to 2 % of the market supply of all NdFeB magnets. They have a similar energy density to *S-NdFeB* (3.3) magnets and are usually prepared into ring-shape magnets with strong magnetic anisotropy.

3.6

recyclable neodymium iron boron resource

recyclable NdFeB resource

resource usually collected from end-of-life (EOL) and manufacture processed S-NdFeB, B-NdFeB, and D-NdFeB magnet components, containing a high concentration of rare earth and other valuable elements, where the popular rare earth elements (REE) include neodymium (Nd), praseodymium (Pr), dysprosium (Dy) and terbium (Tb)

Note 1 to entry: EOL is a term indicating that a product is at the end of its useful life from the customer's point of view, possibly because the product is broken, expired or fails to meet the customer's needs.

3.7

recyclable neodymium iron boron resource from end-of-life products

recyclable NdFeB resource from EOL products

recyclable NdFeB resources from the end-of-life equipment

3.8

recyclable neodymium iron boron resource from end-of-life products

recyclable NdFeB resource from industrial products

recyclable NdFeB resources generated from the whole industrial fabrication process

Note 1 to entry: Recyclable NdFeB resources from industrial products can be further subdivided into solid-state *NdFeB magnet scraps* (3.9) and solid-liquid mixing *NdFeB magnet sludge* (3.10).

3.9

neodymium iron boron magnet scrap

NdFeB magnet scrap

solid-state *recyclable NdFeB resource* (3.6) produced from manufacturing and machining processes, including large or small bulks and powders

EXAMPLE Leftover raw materials in alloying and sintering processes, residual bulk or powder, unqualified or defective products from sintering or cutting in the preparation of *S-NdFeB* (3.3) magnets

3.10

neodymium iron boron magnet sludge

NdFeB magnet sludge

recyclable NdFeB resource (3.6) from the machining process of *S-NdFeB* (3.3) magnets, which is often mixed with cooling fluids and other impurities

Note 1 to entry: Grinding, cutting, slicing, drilling and chamfering operations are some of the extensively used machining processes of S-NdFeB. In these processes, except target product, some small particles, flakes, chips and slurry are also produced and discarded together with different kinds of water-based or oil-based coolant.

3.11

coating

surface layer of S-NdFeB, B-NdFeB or D-NdFeB that avoids the oxidation of *NdFeB* (3.2) magnets

EXAMPLE NdFeB magnet coatings can be metal, alloy or epoxy.

4 Classification and codes

4.1 General

The classification of recyclable NdFeB resources in this document is based upon three sources: S-NdFeB (see 4.2), B-NdFeB (see 4.3) and D-NdFeB (see 4.4), which bear different structural and magnetic properties.

Each kind of recyclable NdFeB resource is further classified into two categories, recyclable NdFeB resources from EOL products and recyclable NdFeB resources from industrial products, according to their sources, characteristics, etc. The recyclable NdFeB resources from industrial products can be further divided into two sub-groups of solid-state scraps such as bulk and powder, and solid-liquid mixed sludge.

4.2 Classification of recyclable S-NdFeB resources

4.2.1 Recyclable S-NdFeB resources from EOL products

Bulk recyclable S-NdFeB resources usually maintain their original magnetic properties and can be in various sizes and shapes depending on the source. According to the magnetic property, size, etc., they can be classified into four classes, as shown in Table 1. The grade should conform to the grade given in IEC 60404-1:2016. The characteristic “same grade” given in Table 1 indicates that the recyclable magnet in a certain package bears a similar magnetic property, i.e. the same magnetic grade, while “mixture of grades” indicates that the NdFeB magnet scraps in one package bear a different magnetic property.

Recyclable S-NdFeB resources from EOL products are sometimes collected according to the end of life equipment. Therefore, the equipment information is also very helpful to determine the contained recycled material, since the grade of S-NdFeB magnets is usually unchanged for a specific make and model. Nevertheless, classifying resources according to the previous application is difficult since there are many fields in which NdFeB magnets are used.

Table 1 — Classification and characteristics of recyclable NdFeB resources from EOL products

Category	Class	Characteristics	Appearance feature	Typical source/examples
Recyclable S-NdFeB resources from EOL products	1	Same grade/application without coating	Large bulk	42SH for generators in wind turbines; 38UH for traction motors of traction-drive lifts
	2	Same grade/application with coating	Small bulk with metallic lustre	EOL voice coil motors; sport motors
	3	Mixture of grades/application without coating	Small bulk with specific shape	Different household small electric motors
	4	Mixture of grades/application with coating		

4.2.2 Recyclable S-NdFeB resources from industrial products

Considering the large production of recyclable NdFeB resources from industrial products, and the huge differences in their characteristics, shapes, rare earth content, recycling methods, trade and transportation, etc., it is necessary to carry out a more detailed classification, as shown in [Table 2](#).

Table 2 — Classification and characteristics of recyclable NdFeB resources from industrial products

Category	Class	Appearance feature	Total REE mass %	Characteristics	Typical source/examples	
Recyclable S-NdFeB resources from industrial products	1	Bulk/ piece	Magnetic leftover bulks and pieces; various shapes	30 to 35	Same grade/grey or dark brown	Machining scraps, unqualified magnetic products
	2				Mixture of grades/grey or dark brown	Machining scraps, unqualified magnetic products
	3	Powder	Dark brown, non-magnetic powder	35 to 45	Small bulk or particles	Smelt slag
	4		Yellow or dark brown; non-magnetic powders	50 to 70	Ultra-fine powders (1 µm to 10 µm)	Jet-milled powders
	5		Yellow or dark brown; non-magnetic powders	30 to 40	Fine powders (10 µm to 100 µm)	Sintered defective powders
	6		Yellow or dark brown; non-magnetic powders	30 to 35	Coarse powders or particles (20 µm to 300 µm)	HD or melted powders
	7	Sludge	Black sludge	20 to 30	With oil and little impurities	Slicing sludge
	8		Dark brown sludge	20 to 30	With water	Grinded sludge
	9		Grey or dark brown sludge	15 to 25	With oil and silicon carbide	Multi-wire cut sludge
	10		Grey-white sludge	5 to 15	With water	Wire-cut or chamfered sludge

4.3 Classification of recyclable B-NdFeB resources

Recyclable B-NdFeB resources can be classified into two categories: those from EOL products and those from industrial products, as shown in Table 3. These two categories can be further divided into classes with respect to their magnet properties (same grade and mixture of grades) and binder types (epoxy or nylon). Since there is only a small production of recyclable B-NdFeB resources from industrial products, their classification is similar to that of EOL products.

Table 3 — Classification and characteristics of recyclable B-NdFeB resources

Category	Class	Characteristics	Total REE mass %	Appearance feature	Typical source/examples
I. Recyclable B-NdFeB resources from EOL products	1	Same grade	28 to 32	Magnetic EOL products in bulk with binder of epoxy	Magnets disassembled from spindle motor and/or hard disk drives
	2	Mixture of grades			Magnets disassembled from different kinds of motors and other applications
	3	Same grade	25 to 30	Magnetic EOL products in bulk with binder of nylon	Magnets disassembled from different kinds of motors and other applications
	4	Mixture of grades			
II. Recyclable B-NdFeB resources from industrial products	5	Same grade	28 to 32	Magnetic leftover bulks or pieces with binder of epoxy	Unqualified magnetic products
	6	Mixture of grades			
	7	Same grade	25 to 30	Magnetic leftover bulks or pieces with binder of nylon	
	8	Mixture of grades			

4.4 Classification of recyclable D-NdFeB resources

Recyclable D-NdFeB resources can be classified into two categories: those from EOL products and those from industrial products, as shown in Table 4. These two categories can be further divided into classes with respect to their magnet properties (same grade and mixture of grades).

Table 4 — Classification and characteristics of recyclable D-NdFeB resources

Category	Class	Characteristics	Appearance feature	Total REE mass %	Typical source/examples
I. Recyclable D-NdFeB resources from EOL products	1	Same grade	Magnetic EOL products in bulk	30 to 35	Magnets disassembled from servo motors in robots
	2	Mixture of grades			Magnets disassembled from different kinds of motors and other applications
II. Recyclable D-NdFeB resources from industrial products	3	Same grade	Magnetic leftover bulks or pieces	30 to 35	Unqualified magnetic products
	4	Mixture of grades			

4.5 Codes of recyclable NdFeB resources

Codes comprising a combination of eight digits and letters, written as “RRExxxxxxxx(&)", shall be used to describe the recyclable NdFeB resources. The first four digits shall be 0101 in accordance with ISO 22450:2020, which means "Nd-based recyclable NdFeB resources". The fifth letter shall be S, B or D to indicate the type of the NdFeB. The sixth digit shall identify the category of the recyclable NdFeB resources. The last two digits shall indicate the class, i.e. the quality of the recyclable resources. The symbol “&” shall

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indicate the corresponding grade conforming to IEC 60404-1 if the recyclable resources come from the same grade. For recyclable NdFeB resources from a mixture of grades, it is not necessary to show "&".

Figure 2 gives an example illustrating a code for recyclable NdFeB resources. The classification for all kinds of recyclable NdFeB resources and their corresponding codes is given in Table 5.

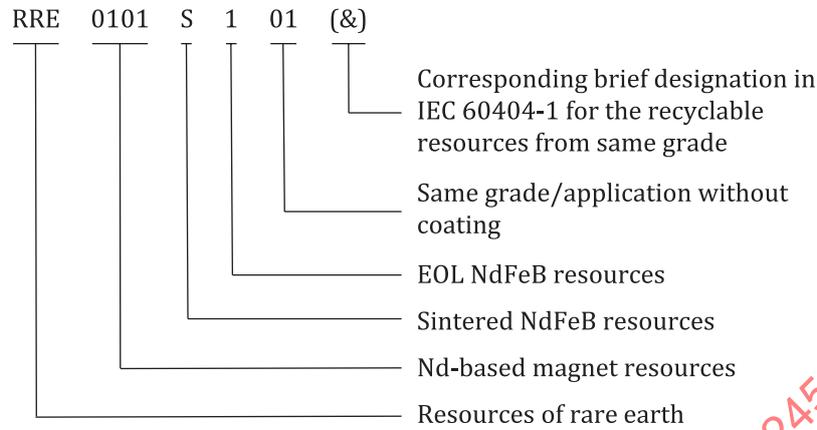


Figure 2 — Example of a code for recyclable NdFeB resources

Table 5 — Classification and codes of all kinds of recyclable NdFeB resources

Classification	Codes	Descriptions
RRE0101-S1xx		Recyclable S-NdFeB resources from EOL products
	RRE0101S101(&)	Same grade/application without coating
	RRE0101S102(&)	Same grade/application with coating
	RRE0101S103	Mixture of grades/application without coating
	RRE0101S104	Mixture of grades/application without coating
RRE0101-S2xx		Recyclable S-NdFeB resources from industrial products
	RRE0101S201(&)	Same grade/grey or dark brown, a mass fraction of 30 % to 40 % REE content
	RRE0101S202	Mixture of grades/grey or dark brown, a mass fraction of 30 % to 40 % REE content
	RRE0101S203	Dark brown, small bulk or particles, a mass fraction of 30 % to 60 % REE content
	RRE0101S204	Yellow or dark brown ultrafine powders, a mass fraction of 25 % to 50 % REE content
	RRE0101S205	Yellow or dark brown fine powders, a mass fraction of 25 % to 50 % REE content
	RRE0101S206	Yellow or dark brown other powders or particles, a mass fraction of 25 % to 80 % REE content
	RRE0101S207	With oil and little impurities, a mass fraction of 22 % to 30 % REE content
	RRE0101S208	With water, a mass fraction of 15 % to 25 % REE content
	RRE0101S209	With oil and silicon carbide, a mass fraction of 8 % to 15 % REE content
	RRE0101S210	With water, a mass fraction of 1 % to 5 % REE content
RRE0101-B1xx		Recyclable B-NdFeB resources from EOL products
	RRE0101B101(&)	With binder of epoxy/same grade
	RRE0101B102	With binder of epoxy/mixture of grades
	RRE0101B103(&)	With binder of nylon/same grade
	RRE0101B104	With binder of nylon/mixture of grades
RRE0101-B2xx		Recyclable B-NdFeB resources from industrial products

Table 5 (continued)

Classification	Codes	Descriptions
	RRE0101B201(&)	With binder of epoxy/same grade
	RRE0101B202	With binder of epoxy/mixture of grades
	RRE0101B203(&)	With binder of nylon/same grade
	RRE0101B204	With binder of nylon/mixture of grades
RRE0101-D1xx		Recyclable D-NdFeB resources from EOL products
	RRE0101D101(&)	Same grade
	RRE0101D102	Mixture of grades
RRE0101-D2xx		Recyclable D-NdFeB resources from industrial products
	RRE0101D201(&)	Same grade
	RRE0101D202	Mixture of grades

5 General requirements

5.1 Sampling

5.1.1 General

The sampling methods given in ISO/TS 22451 and ISO 22928-1 shall be used, noting that the various different recyclable resources have specific sampling rules due to their unique characteristics.

5.1.2 Recyclable S-NdFeB resources from EOL products

Recyclable S-NdFeB resources from EOL products shall first be dismantled and separated. Then, the cycled magnet shall be demagnetized. Next, the surface of the magnet shall be de-coated and cleaned. Finally, sampling can be done.

5.1.3 Recyclable S-NdFeB resources from industrial products

5.1.3.1 Solid resources

For solid NdFeB magnet resources, sampling can be done directly without any special pre-treatment. However, resources that are magnetic shall be demagnetized before sampling. In addition, the surface of the magnets should be cleaned.

5.1.3.2 Sludge resources

NdFeB magnet sludge resources are a mixture of type (liquid and solid). It shall be ensured that the sample is safe to handle and does not contain any hazardous components. For this purpose, the pH of the sludge resources shall be checked and neutralized. After safety is guaranteed, the resource shall be prepared for analysis.

5.2 Testing and analysis

The following four kinds of scientific methods shall be applied to test and analyse the recyclable NdFeB resources:

- magnetic measurement by hysteresigraph or vibrating sample magnetometer (VSM);
- REE mass per cent or chemical composition analysis by X-ray fluorescence (XRF) and inductively coupled plasma atomic emission spectroscopy (ICP-OES);
- microstructure observation by scanning electron microscopy (SEM);

— density measurement by the Archimedes method.

5.3 Packaging

Recyclable NdFeB resources should be packaged in a safe way in steel drums or woven bags. For powder, sludge or scraps containing oil, waterproof and/or airtight packaging shall be applied.

5.4 Transportation and storage

Recyclable NdFeB resources shall not be mixed with any littering, explosive, toxic, corrosive and/or radioactive items. The packaged resources are prohibited to crash and expose to the fire and other items that can easily cause combustion and explosion during transportation, handling and storage.

For powder, sludge or scraps containing oil, safety should be strictly guaranteed during transportation and storage.

5.5 Labelling

Labels shall be attached to the packaging of each item of a minimum packaging unit or stock keeping unit (SKU). The label shall be attached to each packing case (box) indicating the following items, in accordance with ISO 22453:

- a) the name of the supplier;
- b) the RRE code;
- c) the net mass;
- d) the date of delivery;
- e) the country and region;
- f) the magnetic properties for EOL and bulk resources with the same grade, if applicable;
- g) the previous application information of the EOL resources before collection, if applicable;
- h) the chemical composition for powder and sludge resources (the content of the heavy and light REE, if preferred);
- i) a safety warning with ISO graphical symbol or international universal pictogram.

6 Acceptance conditions

6.1 Bulk recyclable NdFeB resources with same grade should conform to the grade given in IEC 60404-1. For resources with a mixture of grades, the grade should be agreed between the supplier and the buyer through consultation.

6.2 When delivered, recyclable NdFeB resources shall first pass through a visual detection process to check whether they conform to the requirements given in [Clause 5](#).

6.3 Labels shall contain all the information given in [5.5](#).

6.4 The rare earth components, i.e. the content of each kind of rare earth, especially the heavy and light REE if preferred for powder and sludge resources.

6.5 The buyer shall check the magnetic property or determine the REE mass per cent or chemical composition according to [5.2](#) and shall inform the buyer of the result within one month after receipt of the resources.