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Elements recycling –Communication formats for providing recycling information on rare earth elements in industrial waste and end of life products

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Foreword

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The committee responsible for this document is Technical Committee *[or Project Committee]* ISO/TC *298*, *[Rare Earth]*.

Introduction

The rare earth elements (REEs) are comprised of the lanthanoid series elements plus scandium and yttrium, which have similar chemical and physical properties, are often found in the same ores and deposits. The importance of rare earth elements has increased greatly due to their important roles in high performance and functional applications in permanent magnets, electric vehicles, motors, wind generators, light-emitting diodes (LED), nickel-metal hydride (NiMH) batteries etcetera. Magnets can be also classified into manufacturing methods. The ‘sintered magnet’ has high bulk density because magnetic powders were sintered at the high temperature. The ‘bonded magnet’ is formed by mixing the magnetic powder and binder material such as rubber or plastic. It generally has a lower magnetic property than a sintered magnet. The type of magnet is useful information for recycling procedures.

Magnet accounts for the highest market share of REEs by application. REE-containing multi-component alloys such as $Sm_{62}Co_{38}$, $Sm(Co_{0.69}Fe_{0.2}Cu_{0.1}Zr_{0.01})_{7.2}$, $Sm(Co_{0.67}Fe_{0.22}Cu_{0.1}Zr_{0.07}Ti_{0.01})_{7.1}$, $Sm_2Fe_{17}N_x$, $Nd(Fe,Mo)_{12}N_x$, $Sm_3(Fe,M)_{29}N_x$, sintered $Nd_2Fe_{14}B/\alpha\text{-}Fe$, $Sm_2Fe_{17}N_x/\alpha\text{-}Fe$, PrFeCuB, $Tb_xDy_{1-x}Fe_2$ (x ~0.3) and others are used in permanent magnets. Due to the complexity involved in processing of these magnets, several different manufacturing routes are used. During the production stages, industrial wastes containing rare earth elements are produced and are often recycled. Magnets found in end-of-life (EOL) or broken electronics, hard disk drives, motors, generators, etc., also contribute to waste.

Phosphors and luminescence applications of REE constitute about one third share of the total demand for REEs. Rare-earth elements (REEs) contained in $(La_{0.6}Ce_{0.27}Tb_{0.13})PO_4$, $(Y_{1.94}Eu_{0.06})O_3$, $(Ba_{0.9}Eu_{0.1})MgAl_{10}O_{17}$, $Ca_{0.98}Eu_{0.02}AlSiN_3$, $(Y_{0.98}Ce_{0.02})_3Al_5O_{12}$, etc., are important materials used in phosphor and LED semiconductor technology. The LED manufacturing process is complex and is undergoing much change with the growth of the industry and the changes in demand patterns of associated commodities. During the production stages of LED’s a lot of waste is created which is recycled. End of life LED’s found in broken smartphones, TVs, display panels, cameras, etc., also contribute to waste.

Batteries make up relatively lower amount of the total demand for REES. REE contained multi component alloys such as $LaNi_5$, $La_{0.8}Nd_{0.2}Ni_{2.5}Co_{2.4}Si_{0.1}$, $La_{0.8}Nd_{0.2}Ni_{2.5}Co_{2.4}Al_{0.1}$, and $MmNi_{3.5}Co_{0.7}Al_{0.8}$ are used in rechargeable nickel-metal hydride (NiMH) batteries due to their superior hydrogen storage properties. The production of these NiMH batteries produces waste which is generally recycled. End of life batteries also contribute to waste.

Numerous categories are schematically illustrated in Fig. 1 in which waste can be generated during manufacturing to end of life stage for magnets, LEDs and batteries.

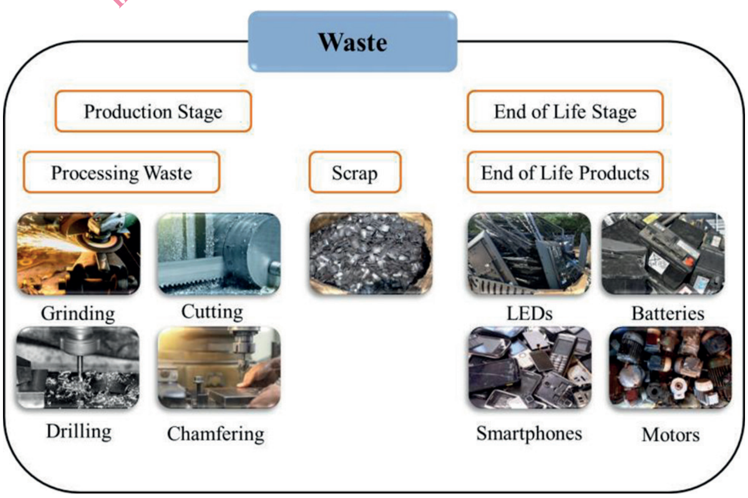

Fig 1 — Waste generation during various processes

Resource scarcity of these valuable commodities is inevitable. Furthermore, piling of waste materials creates environmental and economic problems. A viable option to assure a smooth balance of supply and demand is to recycle these elements.

The following table summarises the expected REE waste stock that will be piled up until 2020 (Binnemans, et al., 2013) and it also gives the indication of recycled REE stock until 2020 by keeping in view the maturity of recycling techniques and industry.

Table 1 — Expected REE waste stocks in year 2020 (Binnemans, et al., 2013)

REE Application	Expected REE stocks in 2020 (tons)	Recycling Process Efficiency	Recycled REE in 2020 (tons)
Magnets	300,000	55%	2 333
Lamp phosphors	25,000	80%	6 600
NiMH Batteries	50,000	50%	1 750

There is a big difference in amount of waste REE generated and it's recycling due to lack of maturity of recycling technologies and communication formats between manufacturers or producers and recyclers. In REE recycling process, an important initial step is identification of products containing REEs. A typical recycling process is depicted in Fig 2.

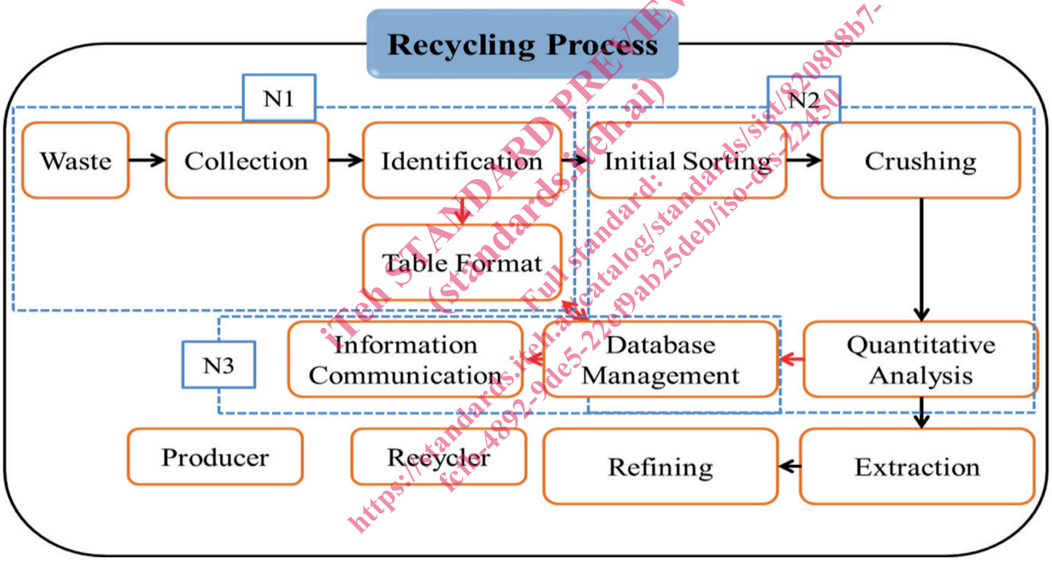

Fig 2 — Typical recycling process. Black arrows represent forward steps, red arrows represent additional steps that are proposed in this standard. N1, N2 and N3 represent the proposed standard documents which are necessary for ensuring smooth demand supply balance for REEs.

This standard (N1) defines REE-related substances that are recycled at the product stage as waste or end-of-life cycled products and suggests ways to facilitate their recycling through identification of the waste composition. N2 relates to measurement methods of REE in industrial waste and end of life products. N3 focusses on management of database obtained from communication with producer, recycler and a management agency for effective recycling. Simultaneous application of N1, N2 and N3 is necessary to assure complete and efficient recycling of valuable REE elements. Combination of N1, N2 and N3 into one document is not suggested due to different scope of each document. Therefore, each of these three aspects of waste management will be covered in an individual standard.

The purpose of this standard (N1, first among three documents) is to specify communication formats to provide information on rare earth elements contained in industrial waste and end of life products from producers or manufacturers to recyclers. A table format, which includes the types of rare earth elements and their concentrations in the industrial waste and end of life products, will be defined in this standard.

Elements recycling –Communication formats for providing recycling information on rare earth elements in industrial waste and end of life products

1 Scope

This International Standard defines the requirements for terms and definition, classification forms to rare earth industrial waste and end of life products. This International Standard suit for rare earth industrial waste and end of life products manufacturer and traders.

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/WD 22444-1 Rare earth – Terms and definitions - --Part 1: Minerals, oxides and other compounds

ISO/WD 22444-2 Rare Earth – Terms and definitions- --Part 2: Rare earth metals and their alloys

ISO/AWI 22927 Rare Earth – Traceability, Packaging and Labelling

IEC 62474, *Material declaration for products of and for the electrotechnical industry*

IEC/TR 62635, *Guidelines for end-of-life information provided by manufacturers and recyclers and for recyclability rate calculation of electrical and electronic equipment*

IEC 62430, *Environmentally conscious design for electrical and electronic products*

ISO 14025, *Environmental labels and declarations — Type III environmental declarations — Principles and procedures*

ISO 14040, *Environmental management — Life cycle assessment — Principles and framework*

ISO 19005, *Document management — Electronic document file format for long-term preservation*

ISO/TC 323 Circular economy

ISO/TC 207 Environmental management

ISO 20400, *Sustainable procurement — Guidance*

3 Terms and definitions

Much attention has been focused on REE waste products such as magnets, phosphors, batteries electrode, catalyst, polishing agent, ceramic additives, and laser source. The Terms and Definitions are summarized based on three important applications which have relatively high REE contents. Also, the terms and definitions given in ISO 21067-1, ISO/WD 22444-1, ISO/WD 22444-2 and the following apply.

3.1 REE

Rare earth element

3.2 REE waste products

The rare earth magnet waste is generating by end-of life cycled application, cutting scraps, and defective products. The popular REE elements on rare earth magnet waste are samarium(Sm), neodymium(Nd), dysprosium(Dy), praseodymium(Pr), and terbium(Tb). The phosphors waste separates LED phosphor and fluorescent lamps phosphor. The popular REE elements on phosphors are cerium(Ce), europium(Eu), terbium(Tb), and erbium(Er). The recovered fluorescent lamps remove Mercury(Hg) and separates into glass, metal, and phosphor, generally. The REE in Nickel-metal hydride(NiMH) batteries are mainly lanthanum(La), cerium(Ce), praseodymium(Pr), and neodymium(Nd).

A high REE containing catalyst is automotive three way catalyst utilizing Ce based Oxygen Storage Capacity material represented by Ce-Zr Mixed Oxide. In addition, cerium is widely used as a nitrogen oxides (NO_x) trap catalysis in diesel vehicles. The cerium oxide (CeO_2)is a key material in the glass polishing process, replacing iron oxide used in polishing glass. REE powders occur in processes of optical components (lenses, prisms), color glass shells, and flat panel display panels due to the chemical-mechanical action principle with high gloss efficiency. The CeO_2 polishing agent is generally containing Pr, too. The yttria-stabilized zirconia (YSZ) is a high-toughness ceramic that stabilizes the tetragonal phase at room temperature by adding Y_2O_3 to ZrO_2. yttrium aluminium garnet(Nd:YAG) laser which has near 1064 nm wavelength is popular mechanical treatment tools.

3.3 Representative applications of REE

3.3.1 REE Magnet

Magnet that contains REE such as Nd, Sm and Dy. The REE magnets have a lot of application areas such as parts of vehicles, home applications, wind turbine generators, high-performance AC servo motors, and computer hard disk drives.

3.3.2 REE Phosphors

A fluorescent substance that contains REE such as Eu, Tb and Ce. REE Phosphors are widely used in LEDs and fluorescent lamps.

3.3.3 NiMH battery

Nickel-metal hydride battery. It utilizes hydrogen storage property of alloys containing REE such as La, Nd and Mm. Rechargeable NiMH batteries are used for hybrid vehicles and as portable batteries for small home appliances.

3.4 Industrial waste

Industrial waste is the waste produced by industrial activity which includes any material that is rendered useless during a manufacturing process such as that of factories, industries, mining and milling operations. The waste from mills and mining operations is not a subject of this standard. The industrial waste dealt with in this standard can be subdivided into following categories:

3.4.1 Processing Waste

The processing waste comes from preparation, processing operations with magnets, fluorescent powder, rare alloys, etc, including of chips, flakes, broken pieces, powders,etc which could be recycled by metallurgical methods to get valuable elements .

3.4.2 Scrap

Scrap consists of recyclable materials left over from product manufacturing ~~and consumption.~~ Unlike waste, scrap has monetary value, especially recovered metals, and non-metallic materials are also recovered for recycling.

3.5 End of life products

End-of-life (EOL) is a term used with respect to a product supplied to customers, indicating that the product is in the end of its useful life from the customer's point of view. This should be because the product is broken, no longer functions properly, or no longer satisfies the customer's requirements.

3.6 at. %, wt. % TREE (Total rare earth element content)

Atomic percent, weight percent

4 Forms of REEs in industrial waste and end of life products

Significant quantities of REEs are recycled in industrial waste and end of life products which can be recycled to ensure smooth balance between supply and demand chains. Representative forms of REEs in industrial wastes discussed below.

4.1 In RE magnets

During powder production whether pre-alloyed or post alloyed a lot of flakes are produced which are recycled. Similarly powder size greater or smaller than the required size is also recycled. Later screening operation also creates waste powder which is recycled along with cleaning solutions. Machining operations like grinding, cutting (slicing), drilling and chamfering operations along the assembly line produce waste in the form of chips, flakes and broken magnet pieces. Extremely small chips are recycled along with coolants used during these manufacturing operations. During fabrication of rare earth magnets, 20~30% of the raw material in the form of processing waste and scrap can be recycled

End of life RE magnets are found in broken motors, generators, hard disk drives, electronics etc. Being relatively old, these magnets have often developed oxide layers, corrosion, etc.

4.2 In light-emitting diodes

During the manufacturing of LEDs various processes include glass cutting, thin film application, and encapsulation produce waste in the form of broken glass pieces, thin films, powder which is recycled. Often these REEs are combined with organic and inorganic wastes.

End of life LEDs are found in almost all kind of broken modern electronics and contain REEs in the form of oxides and other compounds.

4.3 In nickel-metal hydride batteries

Industrial waste from batteries is produced during electrode manufacturing, assembling, packing and handling in the form of broken or corroded electrode pieces, broken encapsulations. Often these REEs are combined with organic and inorganic acids from electrolytes and transition element impurities from electrode terminals.

End of life batteries contain REEs in the form of solid waste like broken pieces of electrodes and liquid slurries from electrolytes.

4.4 Others

Waste slurry containing Ce are generated in polishing in glass industry and in production process of catalysts. Yttrium (Y), which is used for dental materials, laser light sources, etc., is generally not recycled due to poor economics and the absence of guidelines and it is generally recycled in every form..