MATERIAL MATTERS

Professor Dr Carlo Burkhardt of Pforzheim University, Germany, explains the circular economy for rare earth magnetic materials

Magnets are among the most crucial materials for a modern lifestyle as they are integral to energy conversion across the renewable energy and electric mobility sectors. The strongest type of magnets currently available, rare Earth (RE) magnets are used not only in the high-tech sector but in a wide range of everyday applications, including medical devices, motors and various consumer electronics devices. Demand, therefore, is high. There is typically a choice here between either samarium-cobalt magnets, which are relatively expensive, or the stronger neodymium-iron-boron (NdFeB) magnets, having a wider field of application. Both are based on an RE material, but even though the alloying constituents of RE magnets have been classified as EU critical raw materials, Europe is largely dependent on external sources of RE metals as 90% are produced outside of the EU.

There is still no circular economy to reuse and capture value for these materials. With the predicted need for RE magnets more than doubling in the next ten years, this problem becomes ever-more urgent. At present, the only industrially available way to recover end of life (EOL) magnets from waste streams of electric and electronic equipment is by shredding, recycling by chemicals, and pyrometallurgical routes, which are expensive and energy-intensive. Another problem is that the quality of the recollected materials varies significantly, especially with respect to alloying constituents and state of corrosion and employed corrosion protection, with no classification system for recyclate grades of EOL NdFeB magnets. With current recycling rates under 1%, several research groups in Europe now look at how existing resources could be used more efficiently.

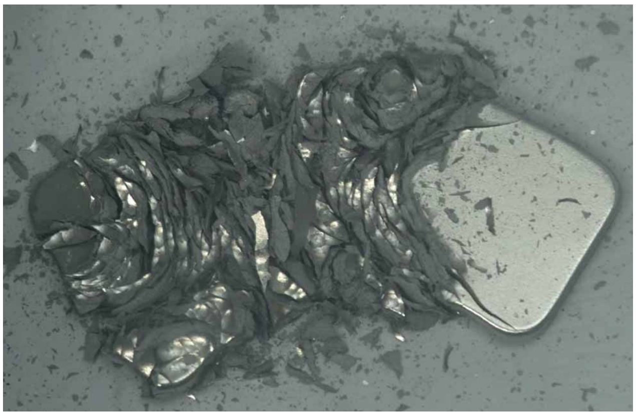

Fig. 1 Hydrogen processed voice coil magnet of a computer hard disk drive

Professor Dr Carlo Burkhardt

The Institute for Precious and Technology Metals (STI) at Pforzheim University in Germany was originally founded in 1996 as the Institute for Jewellery Technology, at that time the key industry in the world-famous 'Golden Town of Pforzheim'. With the evolution of this industrial sector and its companies into industrial high-tech precision technology, including high-end forming, stamping and coating processes, the STI extended its focus to the analysis and characterisation of non-precious alloys and technology materials, thin film coatings and life endurance testing. Today the STI is a renowned, accredited materials testing laboratory equipped with state-of-the-art equipment, including high-resolution optical and laser microscopy, HI-RES SEM/EDX/XRD microscopes, various dedicated mechanical testing facilities and life endurance test rigs. A lab for materials development which includes sintering and smelting furnaces allows alloy development, investigation and optimisation of hydrogen and heat treatment procedures. A complete range of mechanical aftertreatments completes the portfolio of the STI.

With its new leader, Professor Dr Carlo Burkhardt, who has been active in the field of RE magnets for more than 30 years, the STI extended its activities to material efficient production processes for RE magnets. The Horizon 2020 REProMag project (FOF 2-2014, GA #636881), which Burkhardt co-ordinates, examines how the existing RE resources can be used more efficiently. It is based on the idea of creating a closed material loop, where the waste currently existing in the EU is re-used, thus giving a greater degree of independency from the primary material controlled by China. The newly developed SDS process (shaping, debinding and sintering) starts with the recycling of the material gained from waste electrical and electronic equipment (WEEE), where the magnet is separated from the electronic equipment as completely as possible and treated by the hydrogen processing of magnetic scrap (HPMS) process, which was developed by the Magnetic Materials Group of the University of Birmingham, UK, in a preceding EU-project (REMANENCE, NMP2-SE-2012-310240).

The HPMS treatment can be compared to the effect of ice forming on the road in winter in that ice has a larger volume than water and thereby causes cracks in the road. Hydrogen on neodymium (Nd) in an RE magnet has a similar effect, forming a hydride which

Fig. 2 Pforzheim University Campus

causes volume expansion – so this cracks the material apart and breaks it into a non-magnetic powder, which can be easily separated from the other components in the hard disk drive of a computer, for example.

Powder power

The next step is to use this powder to produce RE magnets. Current production routes are not always efficient in the use of the RE materials, as very often the magnets are brought into shape by

Fig. 3 SDS magnets are complexly shaped and strong

grinding and/or eroding, leaving a large amount of production waste. The highly innovative SDS route is a waste-free net shape process, wherein the magnets are brought into shape either by injection moulding (large quantities) or additive manufacturing (small quantities and prototypes). The SDS process starts with a feedstock, which is a blend of the hydride magnetic powder and a complex formula of polymers. The shaping process on standard injection moulding machines allows complexly shaped magnets, with the runners and sprues directly milled and re-used at the injection moulding machine. Today the applications are often built around conventional shapes (as the grinding/eroding process is cumbersome and expensive) as the waste-free SDS process allows new and innovative solutions with maximum material efficiency.

in the next processing steps, and in order to obtain a fully dense magnet, the binder (which is only needed for shaping and does not remain in the magnet as with polymer bonded magnets) has to be removed. This is the tricky part of the operation as Nd is not only highly reactive with hydrogen (which is good for the recycling and milling step), but with carbon and oxygen, and if minimum amounts of either are exceeded, the magnetic properties deteriorate very quickly. The special binder composition, tailored processing parameters and protective gas atmospheres applied during the SDS treatment, however, prevent the pick-up of these elements and, after a subsequent sintering process, the SDS magnets have comparable properties to conventionally sintered magnets. Made from recycled material, magnetic properties of around 95% compared to new material with the same chemical compositions are possible – the 5% loss resulting mainly from oxidation of the Nd-rich phase in the

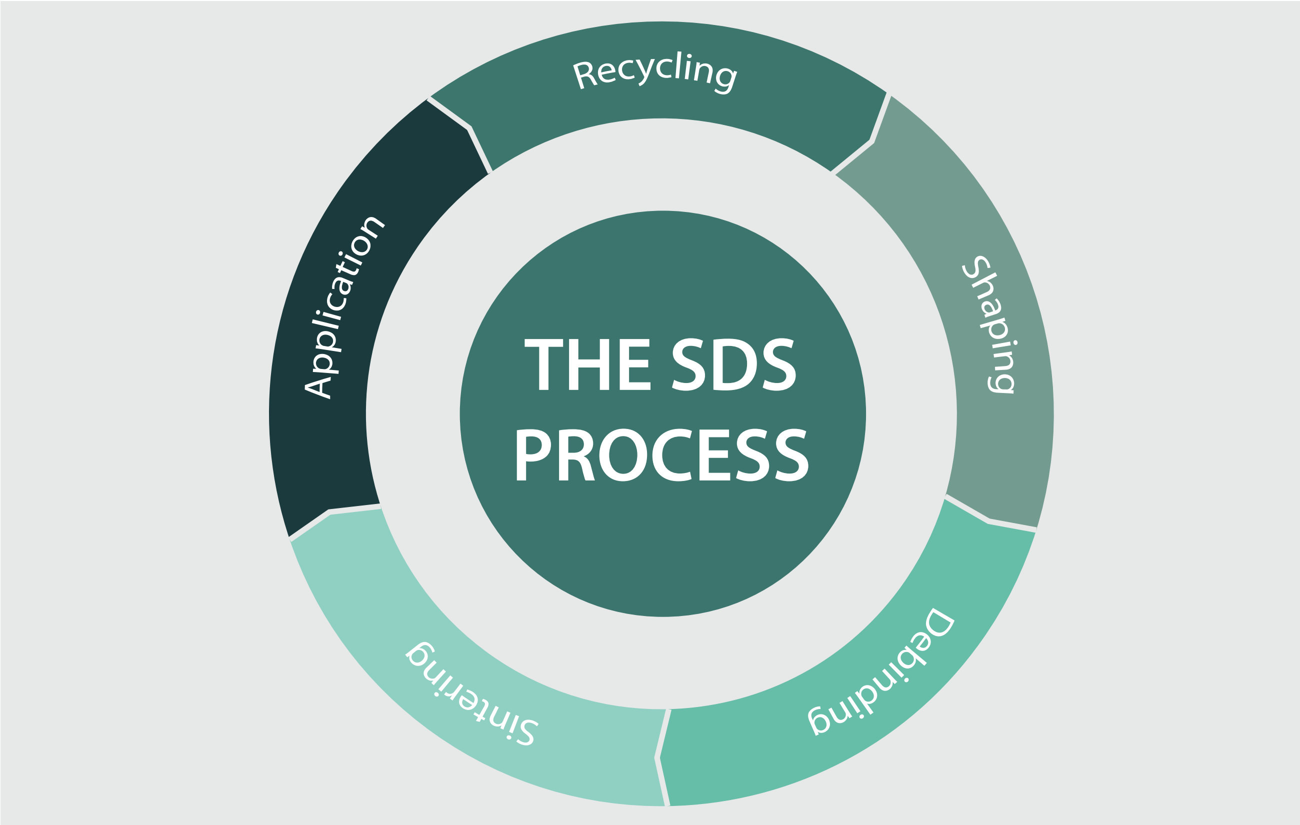

Fig. 4 The SDS process – a circular economy approach

magnets during their lifetime. By compensating this loss with the addition of new Nd-material in a range of about 2%, the original magnetic properties can be achieved.

With these results, REProMag (which was selected by the European Commission as a 'European Success Story', winning the prestigious EcoTech award of the German state of Baden-Württemberg in 2017 and being nominated for the German State Award for Raw Material Efficiency 2017), offers a clean and effective way to produce complexly shaped permanent magnets with highly magnetic, waste-free energy products from recycled material. Providing exciting results, REProMag's SDS process, however, is just a little piece of the puzzle on the way to creating a true circular economy of permanent magnets, with a lot of questions currently still unanswered.

Recycling resolutions

A lack of transparency in materials flows along the recycling chain, and illegal and dubious export streams result in greatly reduced amounts of recycled material. Because of the high variance in primary production methods of magnets, and in the mining of raw materials, it is very difficult to assess the true carbon and energy footprints of magnets now entering the EU. Additionally, and depending on their origin, purpose, place of installation and operational lifetime, the qualities of recollected magnets vary significantly, especially of alloying constituents, state of corrosion, coatings and other residues. As these differences influence the quality and process stability for recycled magnets, innovation must be embedded into broader contexts, including regulatory innovations, to improve knowledge of products and materials in order to increase the current recycling rate of RE materials from under 1% to values of at least 30%, as is common for other technology metals such as silver, platinum and palladium.

To make the vision of the circular economy for RE permanent magnets real, first measures must include:

- Identification of different types of scrap magnets and levels of contamination;
- Measures to deal with impurities in waste streams;
- Fluctuations in properties of recycled materials of varying compositions; and
- Recycling-friendly designs.

In a systematic approach to overcome the barriers currently hindering a successful circular economy for NdFeB-type magnets on an industrial scale, it is necessary to supply technical solutions throughout the circular system, combined with social innovation approaches of standardised labelling of magnet qualities, the introduction of recyclate gradings, and best practice recommendations. Therefore, with other scientific and industrial partners, the STI is planning projects to facilitate the recycling of NdFeB magnets with high yields at reasonable costs, with low energy consumption and minimum environmental impact by delivering:

- A functional, reliable, easy-to-use eco-labelling system for magnets, allowing clear identification of materials and containing all recycling-relevant information, laying the foundation for a

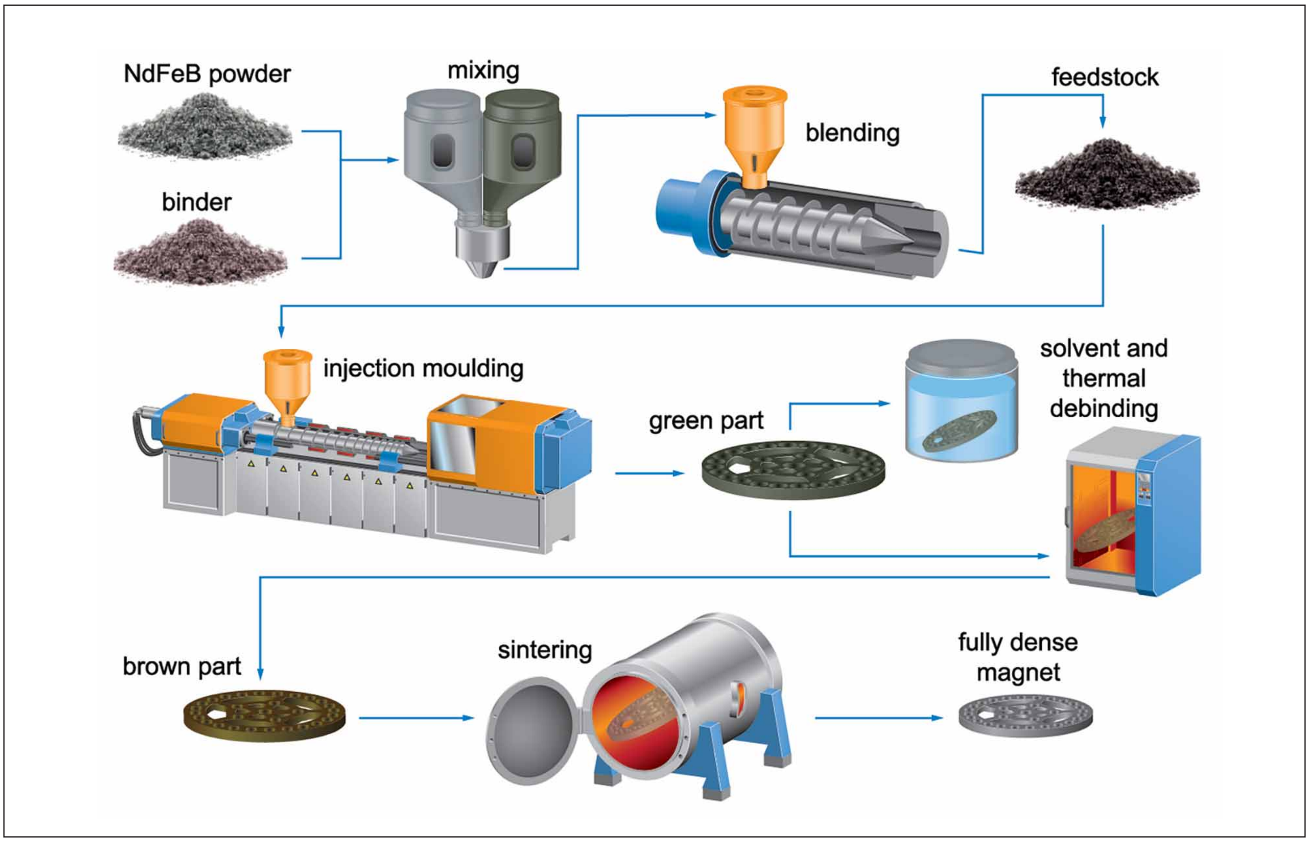

Fig. 5 The SDS processing steps

European standard and reference handbook on environmental labelling for magnets;

- A standardised recyclate grade classification system for end-of-life magnets, giving a clear indication of how cost-effective any magnet can be recycled, and providing valuable information to end users and decision makers about the environmental impact, helping to facilitate efficient eco-design;
- A systematic comparison of currently available coating methods and their suitability for HPMS-treatment at industrial scale, investigation/development of new coating removal methods and classification of the currently employed coatings/residues with respect to recyclability, including an estimation of today's and expected future quantities, to integrate these materials into recycling concepts; and
- An extensive investigation to compare currently available upgrading routes for recycled magnets as a function of the quality of recycled ingot material based on performance, quality and price, benchmarked against requirements of primary materials and assessed for environmental benefits over primary production.

The STI therefore aims to support the EU integrated 'Raw Materials Initiative' (2008) and the European Innovation Partnership on Raw Materials (2012) by introducing a sustainable source of raw materials and increase EU magnet production. The proposed effort could provide a vital contribution to standards for the systematic collection and filing of data across Europe to feed the urban mine inventory and lay the foundation for the build-up of a systematic product inventory of NdFeB resources and expertise on the regional and European scales. Likewise, the proposal aims to develop suitable resource efficiency indicators based on technology, recyclability, economics, environmental impact, distribution models, etc. to provide economic incentives and support for more and better recycling and energy and material use efficiency.

Combined with increasing demand in green technologies and larger quantities of end-of-life electric vehicles and wind turbines magnets being fed into the recycling loop, in the year 2035 a recycling rate of 30% thus seems in reach for RE materials.

HS PF

Professor Dr Carlo Burkhardt
Director of STI
Institute for Precious and Technology Metals
Pforzheim University

+49 7231 28 6063

carlo.burkhardt@hs-pforzheim.de
https://www.hs-pforzheim.de