Mixed Rare Earth-Fe-B sintered magnets

Research project 1 of www.reegain.dk

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Objective

The overall objective of the proposed research project is to develop a high performance rare earth permanent magnet with a (Nd, Pr, Dy) mixture as found in the Tanbreez deposit in Greenland. Secondly a method of recycling magnets in a cradle to cradle (Cradle2Cradle) process will be investigated to prevent the loss of Rare Earth elements in future product cycles of Danish industry. This will be done by **developing and demonstrating a high field alignment of rare earth-Fe-B powder using advanced sintering and magnetization processes**. The project partners have identified the following key scientific and technological issues needed to advance the technology:

Scientific objectives

1. Synthesize magnets of compositions $(Nd_{1-y-z}Pr_yDy_z)_2Fe_{14}B$, where $y < 0.27$ and $z < 0.24$ with limits corresponding to the deposit and to understand the magnetic properties.
2. Magnet production requires a RFeB powder that can have the magnetic hard axis of the grains aligned by an external magnetic field. The scientific objective is to achieve the alignment process in high magnetic fields, while simultaneously maintain the grain orientation using state-of-the-art sintering techniques.
3. Understanding if Dy-enriched surfaces of the RFeB grains can improve the temperature dependence of the coercivity without having to make bulk inclusions of Dy.

Technological Objectives

1. Develop new innovative production methods that can be used to improve the performance of sintered permanent magnets by an optimal usage of the Dy of the Tanbreez deposit.
2. Implement the high field alignment process to give a better utilization of the powder in the magnets. 10 % performance increase has previously been reported in fields of 9 T. [1]
3. Design a high performance magnet strategy and evaluate feasibility of an implementation.

State of the art

The rare-earth elements R belong to the lanthanide series in the Periodic Table: La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb and Lu. They can all be incorporated into the $R_2Fe_{14}B$ (RFeB) compound, which for R = Nd is the permanent magnet with the highest remnant field B_r ever obtained. This is caused by the alignment of the magnetic moments of the Fe atoms and a locking of the direction of the moment to the crystal structure by the Nd. The alignment can be lost by increasing the operation temperature towards the Curie temperature T_C = 312 °C or by applying a magnetic field with the opposite direction in which cause the magnetic moments to flip. RFeB permanent magnets are composed of aligned magnetic domains, but the remnant field B_r will be suppressed to zero if some domains are flipped by an opposite field called the coercive field H_C, thereby making the magnet useless. The last 25 year of research has been focused on optimizing the microstructure of RFeB magnets in order to increase the energy product $(BH)_{Max}$ [2] . The current status is that the remnant field B_r is at 90 % of the theoretical limit, where as the coercivity H_C can still be improved. There are two routes to achieve this goal: 1) decreasing the grain size to avoid magnetic multi-domain and 2) controlling the microstructure and composition of the interface between the grains. Recent result on fine powder have resulted in the "Press-less-process(PLP)", where powder is compacted by tapping, aligned by the field and sintered directly without pressing. This is indicating that new production methods might become available when working with fine powders. A second interesting method is the "Grain boundary diffusion process(GBDP)", where improved H_C with little reduction of B_r was obtained by diffusion of Dy from the surface of a magnet. Combining the two leads to the two-alloy method incorporating nanostructured Dy matrial at the surface of the RFeB grains. We intent to explore this idea further by aligning powder mixtures in high fields up to B = 16 T and to use the Spark-Plasma-Sintering (SPS) methods to control the surface microstructure of the grains.

Societal perspective and relevance

Securing reliable access to rare earth elements (R = La-Yb, Y) is a critical challenge to resource-dependent countries, because many renewable technologies are based on such materials (batteries and motors of electric cars, solar cells and generators for wind turbines). Presently 95% of the production of R elements is in China and a 10 fold increase in market prices have recently been seen due to imposed export quotas. In order to address these challenges, the partner

[1] T. M. Mulcahy, J. R. Hull, E. Rozendaal, J. H. Wise and L. R. Turner, "Improving sintered NdFeB permanent magnets by powder compaction in a 9 T superconducting solenoid", Jour. Appl. Phys. 93, 8680 (2003).

[2] S. Sugimoto, "Current status and recent topics of rare-earth permanent magnets", J.Phys. D: Appl.Phys. 44 (2011), 064001.

Tanbreez of this consortium is working on initiating mining of rare earth minerals in Greenland, which has the potential to supply 10000 tons of rare earth oxides (REO) per year to the market. This will provide enough material for, e.g., 1700 direct drive permanent magnet wind turbines of 3 MW size, making the EU target of 100 GW installed offshore wind capacity by 2030 within reach[3] and will support the strong Danish and EU commitments for reduction of future greenhouse gas emissions.

Research plan

The following work packages (WPs) have been identified as crucial to achieve an optimal rare earth magnet. Each work package is divided into one or more subtasks, each corresponding to either a Ph.D. or other person financed by the project grant with additional manpower being supplied by the partners.

WP1. Materials development and processing

1.1: Literature study of RFeB magnet sintering methods
1.2: Synthesis of experimental RFeB powder similar to Tandbreez source
1.*3: Alignment of RFeB powder in 16 Tesla superconducting magnet and pellet pressing* in order to lock the orientation of the magnetic hard axis of the particles.
1.4: Sintering of RFeB magnets using state-of the art Spark Plasma Sintering (SPS) method.

WP2. Materials characterization

2.1: Characterization of RFeB powder obtained from 3 different sources a) Commercial powder from LessCommonMetals, b) Experimental from WP1 and c) Recycled powder from the technology activities of the consortium (if possible). The determination of the powder properties is important for designing the sintering strategy.
2.2: Characterization and modeling of magnet properties using finite element methods to describe the processes and obtained properties.

WP3. Feasibility of magnets based on the Tanbreez source.

3.1: Formulate road map on implementing a Danish (European) magnet production.

Project partners

The Department of Energy conversion and storage (**DTU Energy Conversion**) will be leading the project and the Head of Program for Electrofunctional Materials, Nini Pryds will be the principle investigator and principle supervisor of the PhD student of the project. **DTU Wind Energy** is participating with Senior Researcher Asger Bech Abrahamsen, who will be responsible of implementing the alignment, sintering and characterization methods and to conduct a feasibility study of the produced magnets in the context of Danish industry and the wind power sector. **Holm Magnetics Aps**, Director Poul Bøjsø has a background in synthesis of RFeB magnets and will act as industrial supervisor of the PhD Student. **FJ Industries A/S** is using sintering for large scale production of metal parts and will contribute with knowledge on the industrial implementation. **Tanbreez Mining Greenland A/S** are working on the pre-qualification of the

[3] B.B. Jensen, A.B. Abrahamsen & M. L. Henriksen, “Influence of Rare Earth Element Supply on Future Offshore Wind Turbine Generators”, Risø International energy conference, ISBN 978-87-550-3903-2 (2011).

Tanbreez deposit in Greenland in order to obtain a mining license. They will contribute with knowledge on the concentration of Rare Earth elements in the Tanbreez deposit and on the expected material supply from the mine. **Sintex A/S** are providing the magnets for the pumps of Grundfoss A/S. They will provide Cradle2Cradle magnet material for further processing and also participate in the processing of the mixed rare earth magnets. **DTI** will work on manufacturing of magnets with complex geometry in the technology project 2 of REEGain and a collaboration on characterization is planned.

Interaction in the REEgain consortium

The properties and some of the magnets produced in the Mixed Rare Earth magnets project is intended exchanged with the cradle to cradle electrical machine design of research project #2 of the REEgain consortium.

Time schedule

The project period is from 1 August 2012 and to 1 August 2016.

Budget

The Mixed Rare Earth Magnet research project has a budget of 4.0 Million DKR

Contact

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