International Conference on Resource Chemistry
March 08-09, 2021

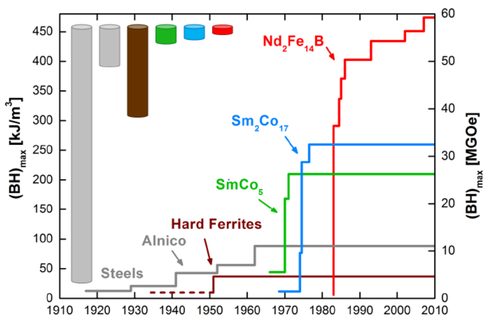
EXPLORING RESOURCE EFFICIENT PRODUCTION ROUTES FOR Nd-Fe-B PERMANENT MAGNETS

Stefan Riegg[1*], Corinna Müller[1], Fansun Chi[2], Enrico Bruder[3], Franziska Staab[3], Peter Groche[2], Clemens Müller[3], Karsten Durst[3] and Oliver Gutfleisch[1]

[1] Functional Materials, Materials- and Geoscience, Technical University Darmstadt, 64287 Darmstadt, Germany
2 Institute PtU, Mechanical Engineering, Technical University Darmstadt, 64287 Darmstadt, Germany
3 Physical Metallurgy, Materials- and Geoscience, Technical University Darmstadt, 64287 Darmstadt, Germany
* Corresponding author. e-mail: Stefan.Riegg@tu-darmstadt.de

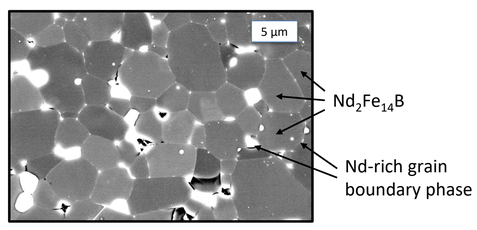
Nd-Fe-B Permanent Magnets

Nd-Fe-B magnets base on the excellent intrinsic magnetic properties of $Nd_2Fe_{14}B$. Transformed to a key microstructure, remanences of up to 1.4 T and energy densities of more than 400 KJ/m^3 can be achieved in sintered magnets, which have the greatest market share (based on $) since more than 10 years.



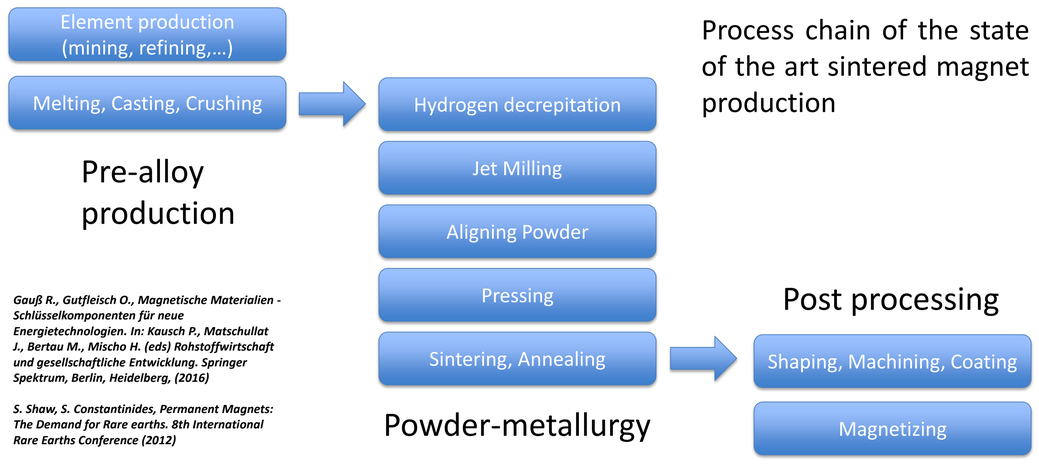
O. Gutfleisch, M.A. Willard, E. Brück, C.H. Chen, S.G. Sankar, J.P. Liu, Magnetic Materials and Devices for the 21st Century: Stronger, Lighter, and More Energy Efficient, Advanced Materials 23, 821-842 (2011)

The production of a typical annual amount of 150.000 tons/year is increasing due to the increasing demand by e-mobility, robotics and energy conversion applications. The magnets possess a high resource criticality by two main reasons, one third of the weight is composed of rare-earth metals (Nd, Pr, Dy, Tb) and the complex production from the ore to the magnet consumes a lot of energy, water and chemicals.



Typical Nd-Fe-B sintered magnet microstructure

K. Löwe, D. Benke, C. Kübel, T. Lienig, K. Skokov und O. Gutfleisch, Acta Materialia 124, 421 (2017)

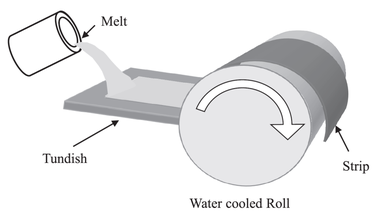


Process chain of the state of the art sintered magnet production

Gauß R., Gutfleisch O., Magnetische Materialien - Schlüsselkomponenten für neue Energietechnologien. In: Kausch P., Matschullat J., Bertau M., Mischo H. (eds) Rohstoffwirtschaft und gesellschaftliche Entwicklung. Springer Spektrum, Berlin, Heidelberg, (2016)

S. Shaw, S. Constantinides, Permanent Magnets: The Demand for Rare earths. 8th International Rare Earths Conference (2012)

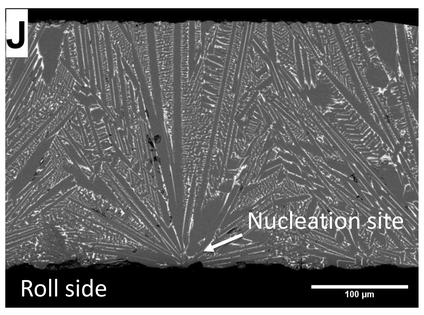
Strip Casting Process



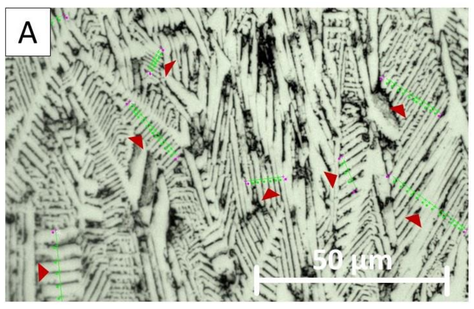
Taken from: K. Yamamoto, R. Murakami, Microstructure Formation on NdFeB Ternary Alloy System for Magnet by Strip Casting Method, J. Japan Inst. Met. Mater. 80, 1 (2015)

In the powdermetallurgical process route for sintered magnets typically the starting materials are strip cast flakes. The microstucture and phase composition obtained by this rapid cooling technique has strong impact on the achievable magnet grade of the final sintered product.

Thus the composition (Nd,Fe,B + Pr,Dy,Co,Al,Ga,…) as well as the casting conditions (temperature, speed of tilting, wheel rotation speed) provide a large parameter space to optimize process and material. The targeted smaller grain size in the sintered magnet leads to an increased coercivity and allows to reduce the amount of heavy rare earth elements (Dy,Tb).



Scanning Electron Microscopy picture of cross section of a strip cast flake, the lamellar structure is formed by $Nd_2Fe_{14}B$ (dark) and Nd-rich grain-boundary phase (light)



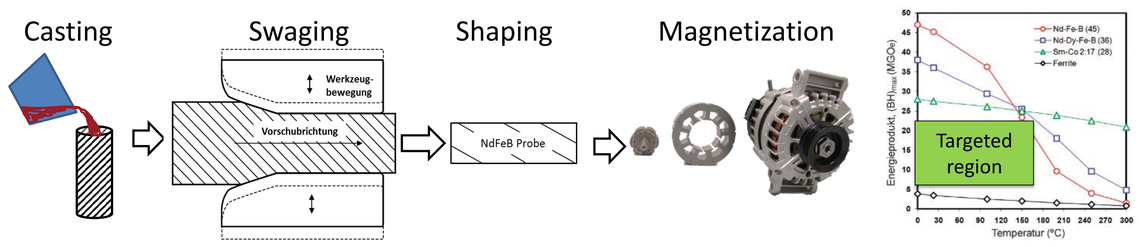
Details of the microstructure by optical microscopy - Intersection method to obtain lamellar thickness values

J. Fidler und T. Schrefl, „Overview of Nd-Fe-B magnets and coercivity (invited),“ IEEE Trans. Magn. 79, 5029 (1996)

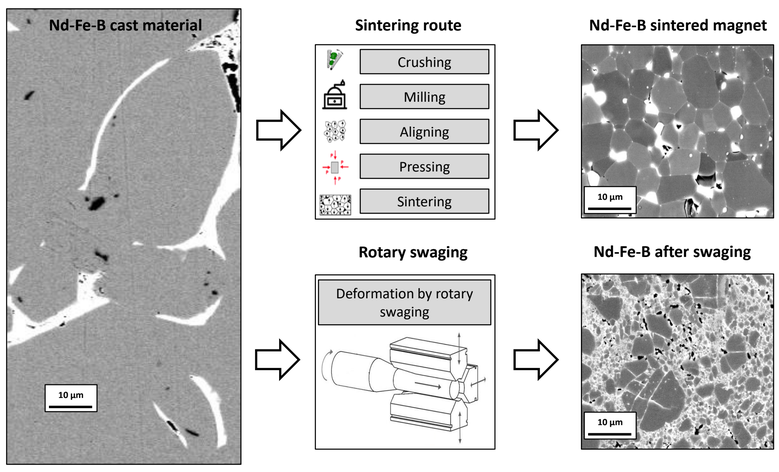
Uestuener, K., Katter, M., and Rodewald,W., “Dependence of the mean grain size and coercivity of sintered nd–fe–b magnets on the initial powder particle size,” IEEE Transactions on Magnetics 42, 2897–2899 (2006)

The adaption of composition and process condition allows to reach a coercivity of 2000 kA/m at room temperature and an improved high temperature (200°C) performance although the amount of Dy by more than 1.5wt%. This work and the upscaling to a commercial production are the goals of the EIT Raw Materials funded project „UPGRADE“ running from 2019 – 2021

Rotary Swaging



A top down approach is used in the project funded by the Pioneer Fund of TU Darmstadt. This means, a cast rod of Nd-Fe-B material is wrapped with a steel cladding and the existing coarse Nd-Fe-B grains are broken down to few micrometer size by a rotary swaging step. Before swaging, the rod is preheated to reach the thixo-state of a partly molten material. This is possible, since the grain boundary phase of the Nd-Fe-B magnet already melts below 700°C. The crushing is supported by a flow of this liquid material to the opening cracks forming ideally a fine grained structure similar to a sintered magnet.



With this method the several process steps can be combined in just one bulk process. In addition, this route is promising for a continuous production compared to the typical state of the art batch production. However, the application of these magnets is limited being isotropic magnetic material with rod-like shapes.

F. Chi, L. Wießner, T. Gröb, E. Bruder, S. Sawatzki, K. Löwe, J. Gassmann, C. Müller, K. Durst, O. Gutfleisch, P. Groche Towards manufacturing of Nd-Fe-B magnets by continuous rotary swaging of cast alloy, Journal of Magnetism and Magnetic Materials, 165405 (2019)

P. Groche, F. Chi, L. Wießner, T. Gröb, E. Bruder, C. Müller, Method for producing a permanent magnet or a hard magnetic material, Patent: WO2019170593A1