TEM study of (Cu,Zr)-enriched SmCo 2:17 magnets used for high temperature applications

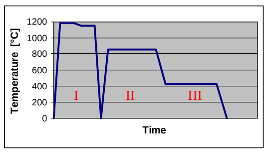
T. Matthias[1], J. Fidler[1], W. Scholz[1], T.S. Rong[2], I.P. Jones[2], I.R. Harris[2], D. Schobinger[3], G. Martinek[3]

[1]Institut für Angewandte und Technische Physik, Vienna University of Technology, Austria
[2]School for Metallurgy and Materials, Unibersity of Birmingham, United Kingdom
[3]Magnequench AG, Lupfig, Switzerland

Motivation

Sm(Co,Fe,Cu,Zr)z permanent magnets are the best choice for operating temperatures above 300° C because of the high magnetocrystalline anisotropy and the high Curie temperature [1,2]. The analysis of the precipitation structure on a nm-scale shows the importance of a uniformly developed cellular structure.

Schematic heat treatment



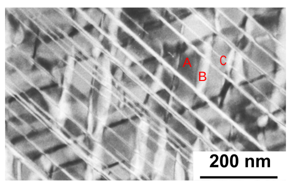
A complex production process, which involves sintering and homogenizing (I), annealing (II) and isothermal aging (III), results in the formation of a cellular precipitation structure which acts as a pinning center for magnetic domain walls [3].

The **cellular precipitation structure** of $Sm(Co,Fe,Cu,Zr)_z$ magnets

A $Sm_2(Co_{1-x}Fe_x)_{17}$ cell matrix phase

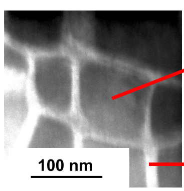
B $Sm(Co_{1-x}Cu_x)_{5-7}$ cell boundary phase

C Lamella phase

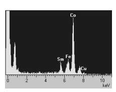


The microstructure as well as the microchemistry are the key parameters for optimising $Sm(Co,Fe,Cu,Zr)_z$ high temperature magnets [4]. The geometry of the cellular structure is determined by the annealing time whereas the elemental composition is influenced by diffusion processes during the whole heat treatment.

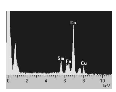
Microstructural TEM study of $Sm(Co_{0.76}Fe_{0.14}Cu_{0.08}Zr_{0.04})_{7.6}$



High angle annular dark field image



cell matrix:
enriched in Fe



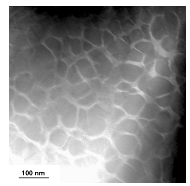
cell boundary:
enriched in Cu, Sm

Experimental

Electron nanoprobe analysis (point analysis and linescans) was performed on a FEI FEG Tecnai 200 keV with a point resolution of 1 nm.

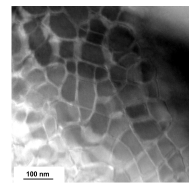
Sample A: $Sm(Co_{0.85}Fe_0Cu_{0.13}Zr_{0.03})_{7.4}$

composition optimised for coercivity at 450° C



Sample B: $Sm(Co_{0.76}Fe_{0.14}Cu_{0.08}Zr_{0.04})_{7.6}$

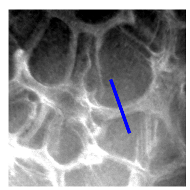
composition optimised for $(BH)_{max}$ at 450° C



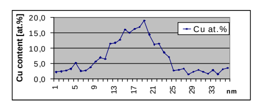
Analysis of the Cu and Zr content of Samples A and B revealed the following data.

	Sample A [at.%]	Sample B [at.%]
nominal Cu content	*11,4*	*6,8*
Cu content in cell matrix phase	3,9	2,9
Cu content in cell boundary phase	15,6	11,9
nominal Zr content	*2,4*	*3,2*
Zr content in cell matrix phase	1,9	0,7
Zr content in cell boundary phase	2,4	1

Cu mainly seggregates in the cell boundary phase. The Cu concentration determines the pinning behaviour of the magnet (e.g. poster GG-14).



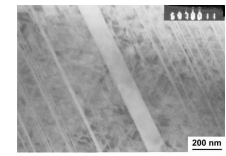
STEM-dark field image



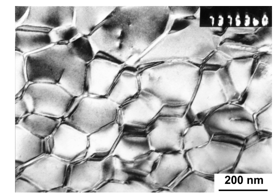
Energy dispersive x-ray linescan across a $Sm(Co,Cu)_5$ precipitation.

The EDX measurements show that the cell matrix phase contains only a small amount of Zr.

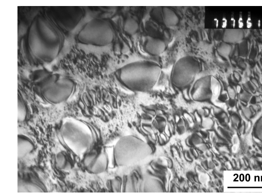
Zr is enriched in the lamella phase. A high nominal Zr content results in the formation of very thick lamellae with a composition of $Zr_{21}Co_{66}Fe_{13}$.



Microstructure and Microchemistry crucially influence the magnetic properties of the mag nets. Only a completely developed microstructure gives rise to a strong pinning field.



complete development



incomplete development

Outlook

The new generation of transmission electron microscopes equipped with field emission guns offer the possibility to analyse the elemental variations on a nm-scale. The influence of the hea treatment on the microstructue and the microchemistry are directly observable, which is very important for the development of strong high temperature permanent magnets.

Summary:

- Microstructure varies in different magnets, depending on composition and heat treatment.
- Uniformity of the cellular structure is essential.
- Minimum thickness of the cell boundary phase is necessary to obtain sufficient coercivity at elevated temperatures.

References:

[1] Strnat, K. J., Rare earth-cobalt permanent magnets, in "Ferromagnetic Materials", edited by E. P. Wohlfarth and K. H. J. Buschow, North-Holland, 1988, vol. 4, pp. 131-209.

[2] C.H. Chen, M.S. Walmer, M.H. Walmer, S. Liu, E. Kuhl, G. Simon, J. Appl. Phys. 83, 6706 (1998

[3] J. Fidler, JMMM 30, 58-70 (1982)

[4] W. Tang, Y. Zhang, G.C: Hadjipanayis, H. Kronmüller, J. Appl. Phys. 87, 5308 (2000)