

Supplementary information

Nanocrystalline Nd-Fe-B anisotropic magnets by flash spark plasma sintering

Fernando Maccari^{1,*}, Tarini Prasad Mishra², Monica Keszler², Tobias Braun¹,
Esmaeil Adabifiroozjaei³, Iliya Radulov^{1,4}, Tianshu Jiang³, Enrico Bruder⁵, Olivier Guillon^{2,6},
Leopoldo Molina-Luna³, Martin Bram^{2,7,*}, Oliver Gutfleisch^{1,4}

1) Technical University of Darmstadt, Institute for Materials Science, Functional Materials,
64287 Darmstadt, Germany.

2) Forschungszentrum Jülich GmbH, Institute of Energy and Climate Research, Materials
Synthesis and Processing (IEK-1), 52425 Jülich, Germany.

3) Technical University of Darmstadt, Institute for Materials Science, Advanced Electron
Microscopy, 64287 Darmstadt, Germany.

4) Fraunhofer Research Institution for Materials Recycling and Resource Strategies IWKS,
63457 Hanau, Germany.

5) Technical University of Darmstadt, Institute for Materials Science, Physical Metallurgy, 64287
Darmstadt, Germany

6) Jülich Aachen Research Alliance, JARA-Energy, 52425 Jülich, 52066 Aachen, Germany.

7) Ruhr-Universität Bochum, Institut für Werkstoffe, 44801 Bochum, Germany.

Corresponding authors:

*Fernando Maccari: fernando.maccari@tu-darmstadt.de

*Martin Bram: m.bram@fz-juelich.de

Starting materials

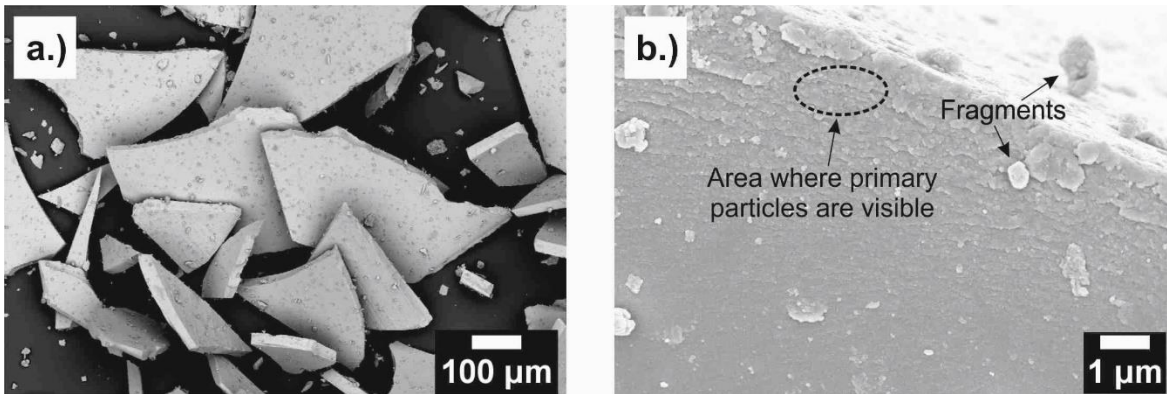


Figure S1: Melt-spun and grinded Nd-Fe-B powder **a.)** Flake-like powder morphology with fragments from grinding adhering on the surface **b.)** Fractured surface of a flake: Fragments from grinding and primary Nd-Fe-B particles can be distinguished.

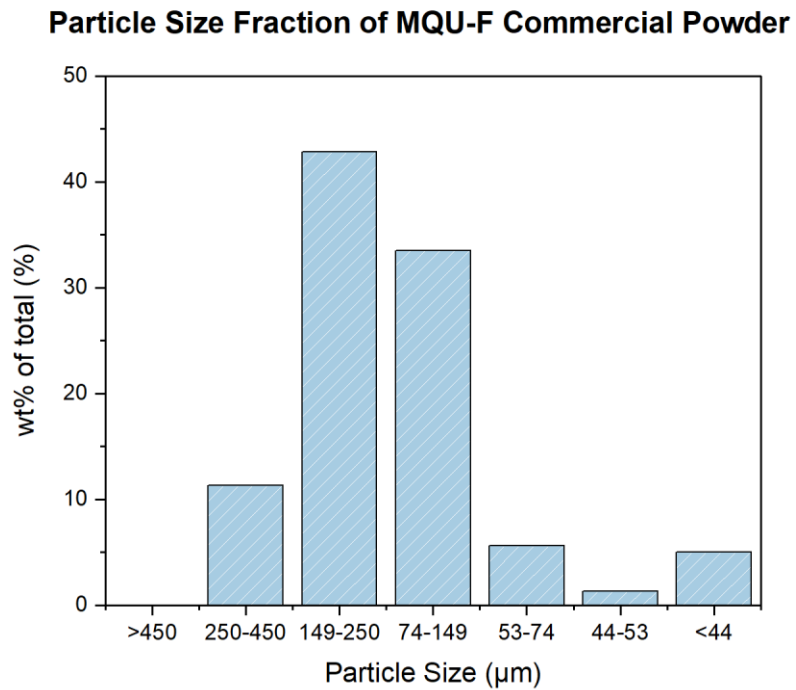


Figure S2: Particle size distribution of the MQU-F starting powder.

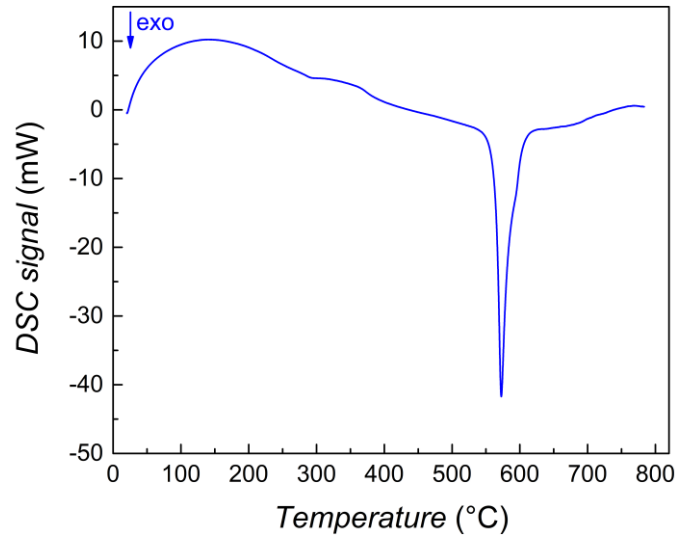


Figure S3: DSC measurement of the starting powder.

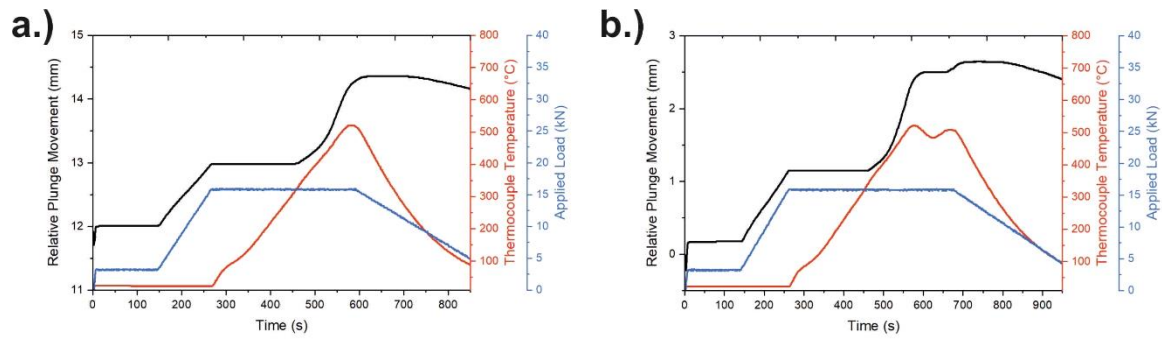


Figure S4: Load-temperature-displacement curves of samples pre-sintered via FAST/SPS at 500°C, 50 MPa **a.)** dwell time 30 s **b.)** dwell time 120 s.



Figure S5: Appearance of the Nd-Fe-B compacts before and after Flash SPS. Due to conducting the Flash SPS cycles without an outer die, the edge of the samples was frayed.

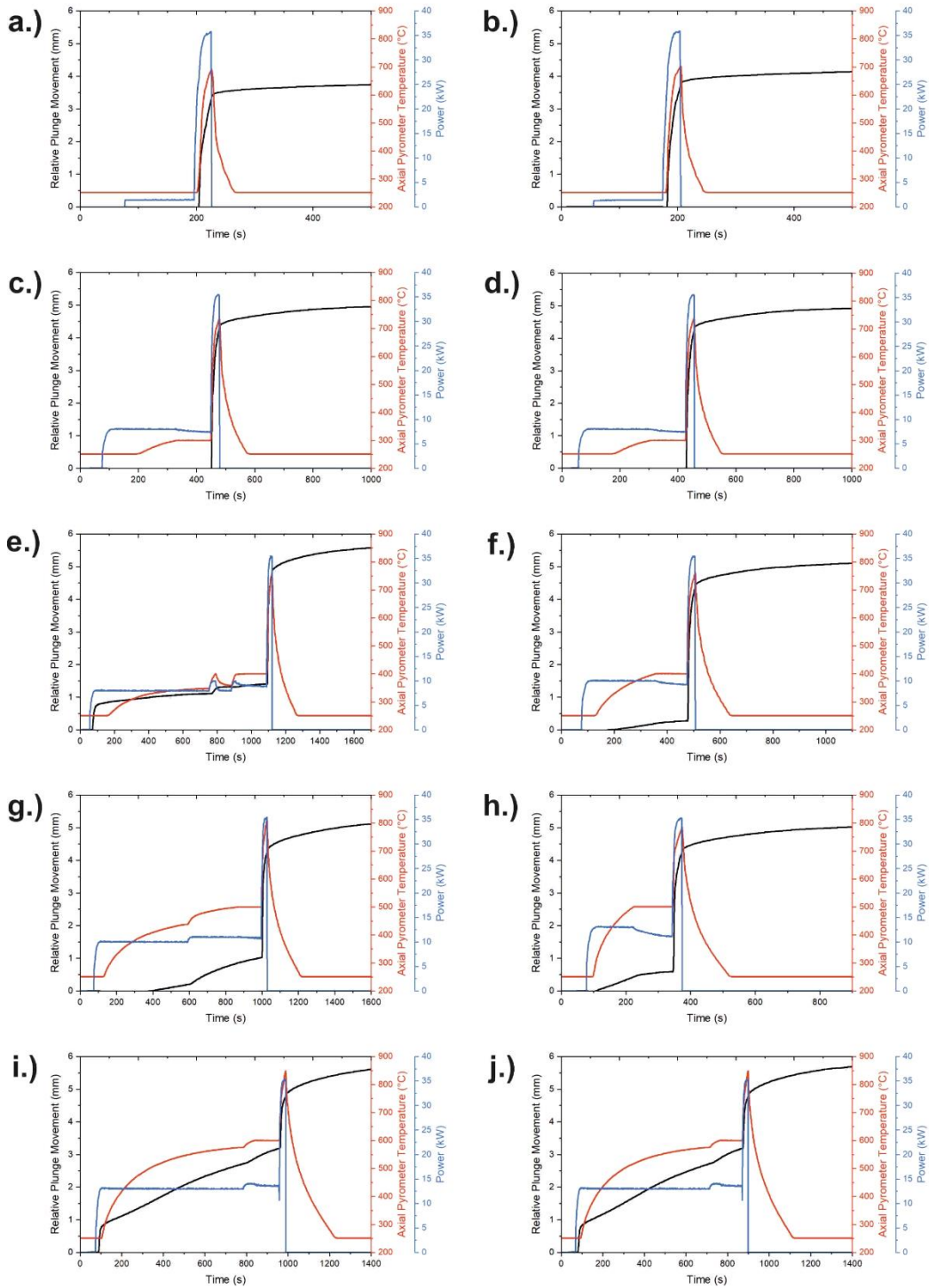


Figure S6: Comparison of Flash SPS cycles: Temperature-power-displacement curves as function of time during pre-heating and subsequent application of the power pulse **a.)** A-30_251 **b.)** B- 120_251 **c.)** A-30_300 **d.)** B-120_300 **e.)** A-30_400 **f.)** B-120_400 **g.)** A-30_500 **h.)** B- F120_500 **i.)** A-30_600 **j.)** B-120_600.

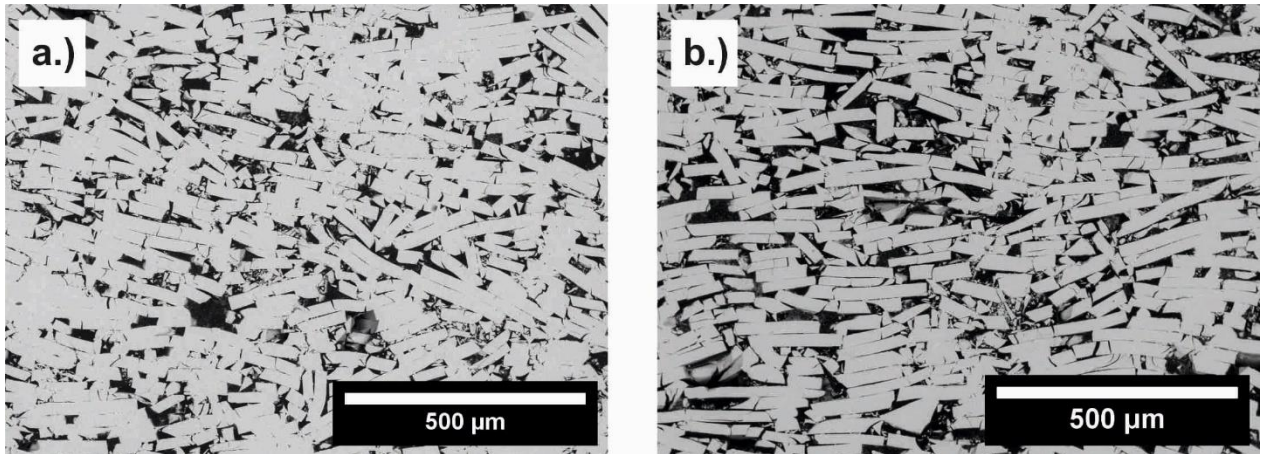


Figure S7: Microstructure of a compact pre-sintered via FAST/SPS at 500°C **a.)** Dwell time 30 s **b.)** Dwell time 120 s. Tilting of powder flakes leads to scattering of porosity in the pre-sintered state.

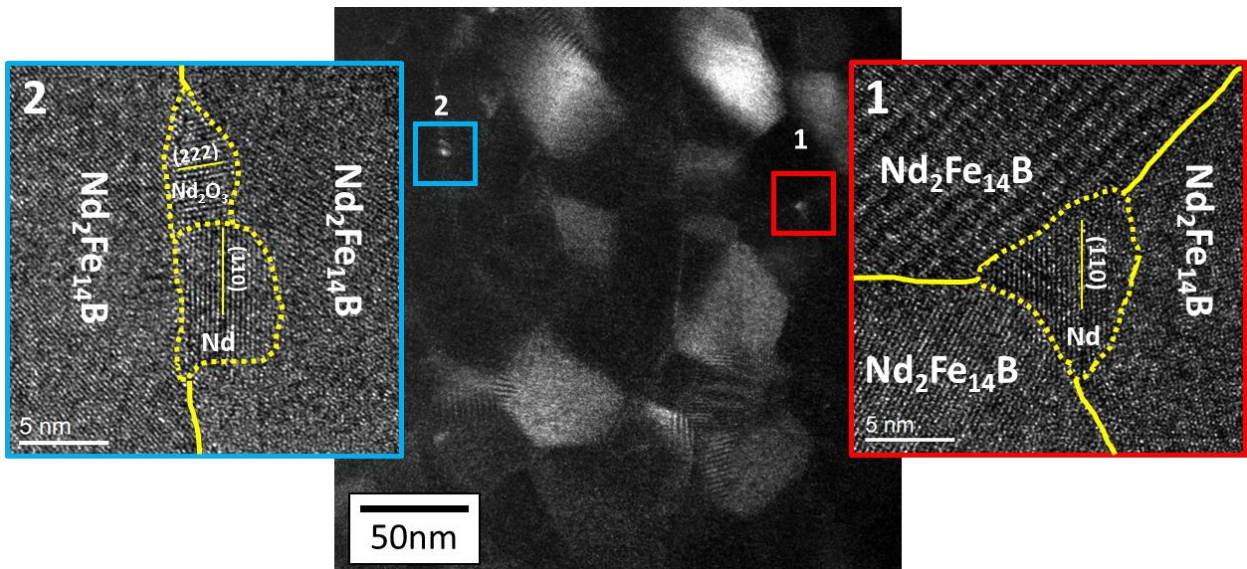


Figure S8: Dark field TEM image of a compact pre-sintered via FAST/SPS at 500°C for 120 s. The selected areas 1 and 2 show high-resolution TEM images with the corresponding phases. On position 1, we observe a triple junction with Nd-dhcp phase (double hcp structure - labelled as Nd) and on position 2, we observe a grain boundary phase containing Nd-dhcp and Nd_2O_3 . Grain boundaries and phase boundaries are highlighted, as well as the orientation of the Nd-rich phases.