Development of Improved Powder for Bonded Permanent Magnets Spherical Powder

AMES LABORATORY

Iver E. Anderson
R. W. McCallum
M. J. Kramer
Ames Laboratory (USDOE), Iowa State University, Ames, Iowa 50011

Support: DOE-BES and DOE-EE-FCVT Program, APEEM
(Susan Rogers,Prog. Mgr.), Contract W-7405-Eng-82.

Development of Improved Powder for Bonded Permanent Magnets Spherical Powder

AMES LABORATORY

Iver E. Anderson — project coordinator, gas atomization, powder processing
222 Metals Development
Ames Laboratory (USDOE),
Iowa State University, Ames, Iowa 50011
Tel: 515 294 9-9781,
andersoni@ameslab.gov

R. W. McCallum — magnetic properties and alloy design
106 Wilhelm Hall
Ames Laboratory (USDOE),
Iowa State University, Ames, Iowa 50011
Tel: 515 294-4736,
mccallum@ameslab.gov

M. J. Kramer — microstructure
225 Wilhelm Hall
Ames Laboratory (USDOE),
Iowa State University, Ames, Iowa 50011
Tel: 515 294-0276,
mjkramer@amesalb.gov

Development of Improved Powder for Bonded Permanent Magnets Spherical Powder

AMES LABORATORY

Working with Ames Laboratory and Intellectual Property

Debra L. Covey
Associate Director
Office of Sponsored Research

311 TASF
Ames Laboratory (USDOE),
Iowa State University, Ames, Iowa 50011
Tel: 515 294-1048
covey@ameslab.gov

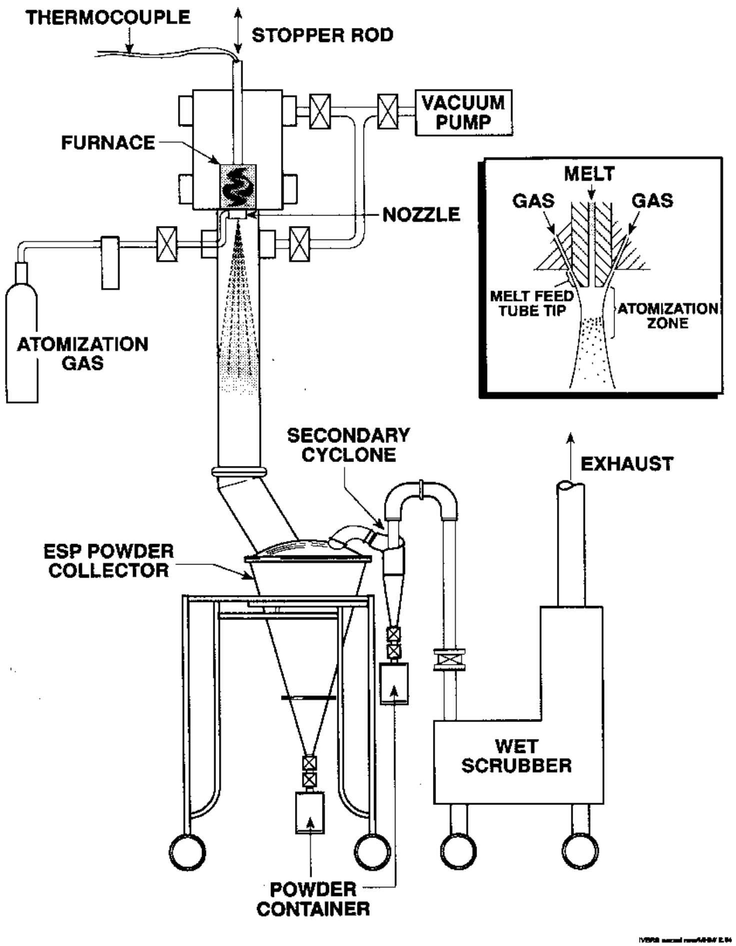
http://www.external.ameslab.gov/oipp/

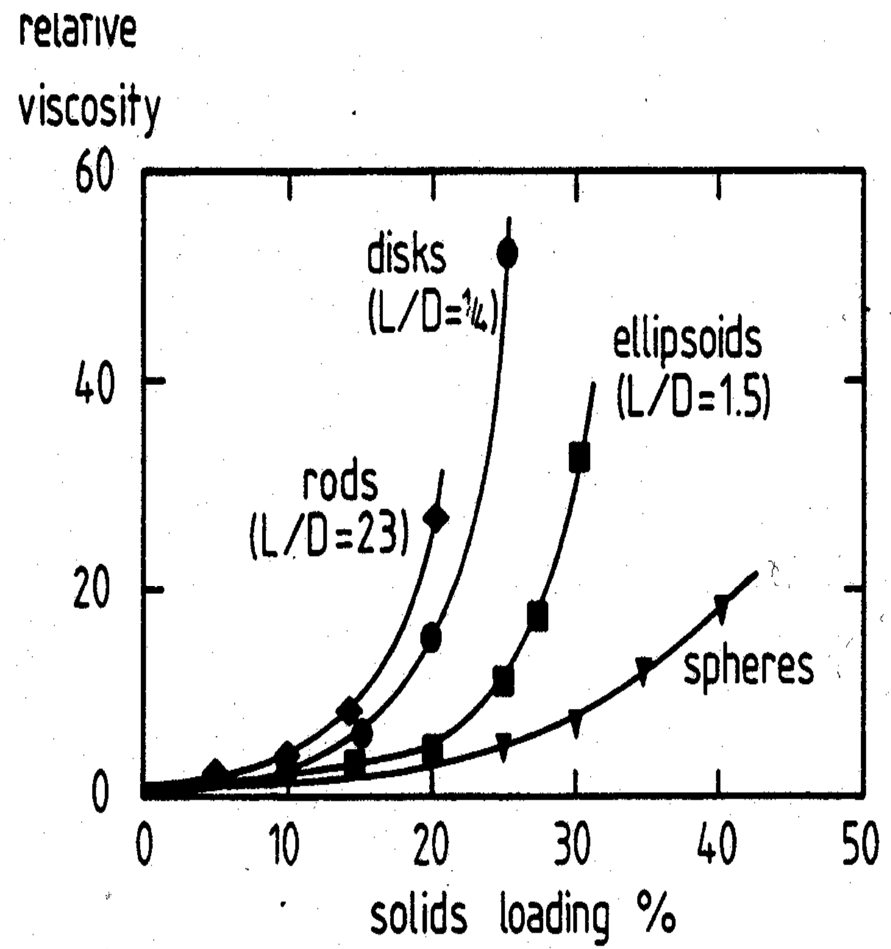
Project Objectives:

AMES LABORATORY

- Develop high performance permanent magnets (PM) for traction motor with internal PM rotor :
  - requires elevated temperature (180-200˚C) operation, minimize cooling needs
  - increased high temperature magnetic performance more critical than RT
- Reduce manufacturing cost of PM traction motors:
  - bonded PM can utilize injection or compression molding technology
    - net shape forming for mass production of rotors
- Achieve high performance and reliability for bonded magnets:
  - increase volumetric loading
  - minimize irreversible magnetic losses (oxidation)

Gas Atomization of Spherical Powder





Overcoming Challenges to Development of Fine Spherical Powder

AMES LABORATORY

- Obstacles to development of fine spherical gas atomized magnet powders
  - Microstructure, process dependent phase compositon
    - Overall quench rate similar to melt spinning at low wheel speeds.
    - Heat flow (3-D radial) within droplet contrasted to melt spinning heat flow (2-D)
  - Chemistry
    - Compositional losses during alloy charge formulation by plasma melting must be accommodated.
    - Compositional (RE) losses during melting of atomization charge similar
      to large scale melt spinning and must be accommodated
    - Challenge of melt handling in gas atomizer with elevated superheat and reactive elements.

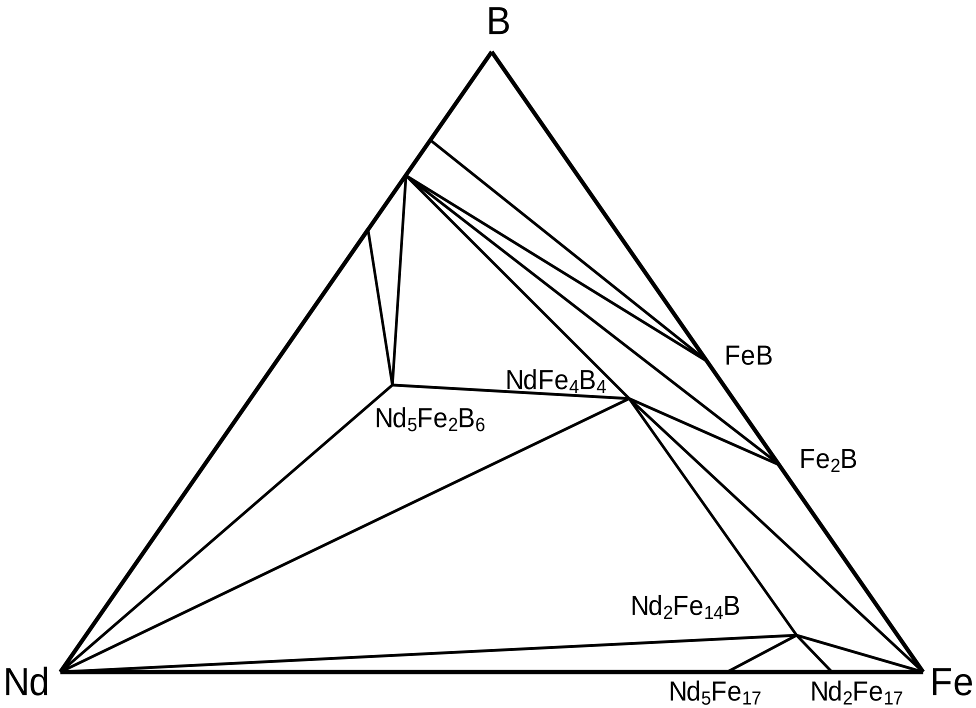
Overcoming Challenges to Development of Fine Spherical Powder

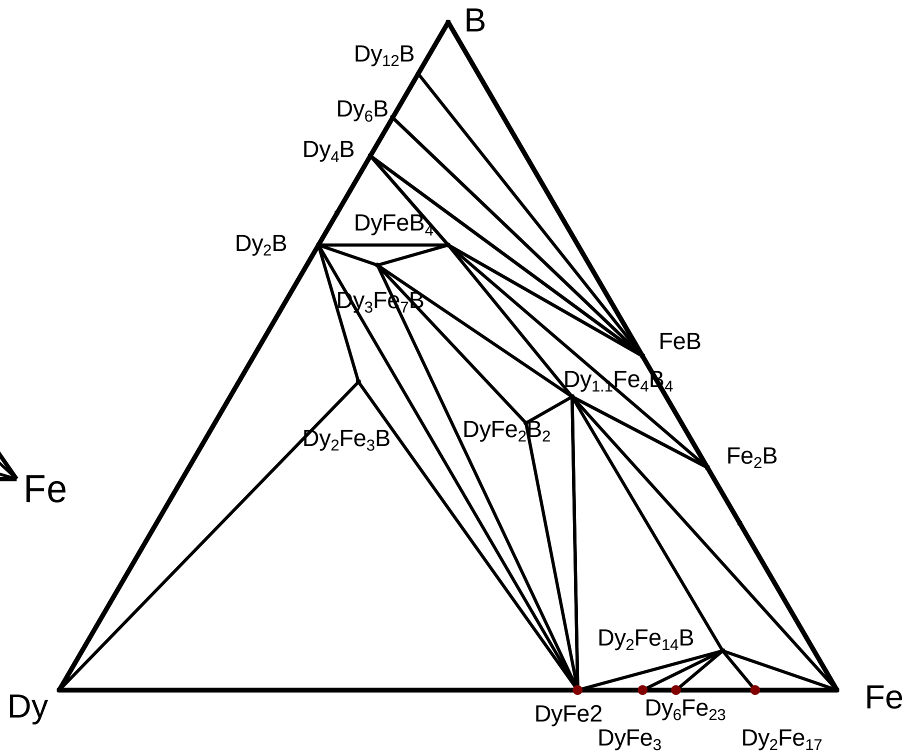
AMES LABORATORY

- Obstacles to development of fine spherical gas atomized magnet powders
  - Stability
    - Significantly higher surface area in as-solidified form
      - Oxidation sensitivity
      - Passivation needed to moderate explosivity
    - Similar surface area of fine spherical powder compared to milled flake
      - Corrosion/oxidation protection needed
  - Processing Cost
    - Experimental atomization run requires 40 times more material and 10 times more labor to produce one run, compared to melt spinning.
    - Full-scale production potentially far cheaper for gas atomization in existing industrial capacity.

Development Scenarios

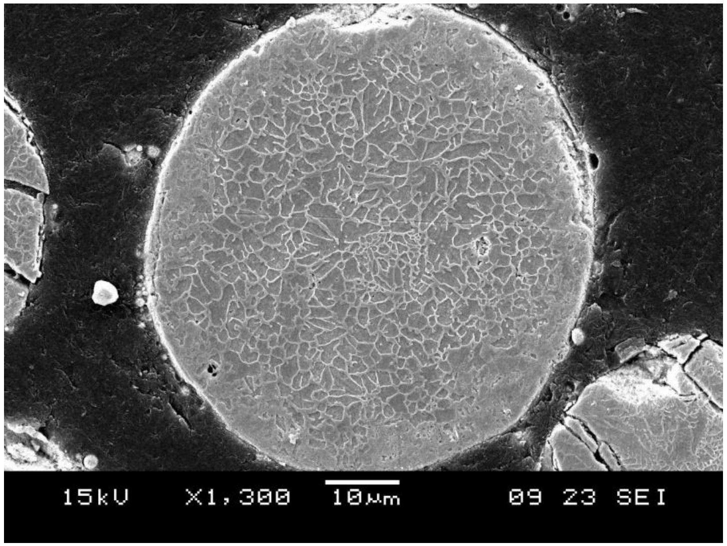
AMES LABORATORY





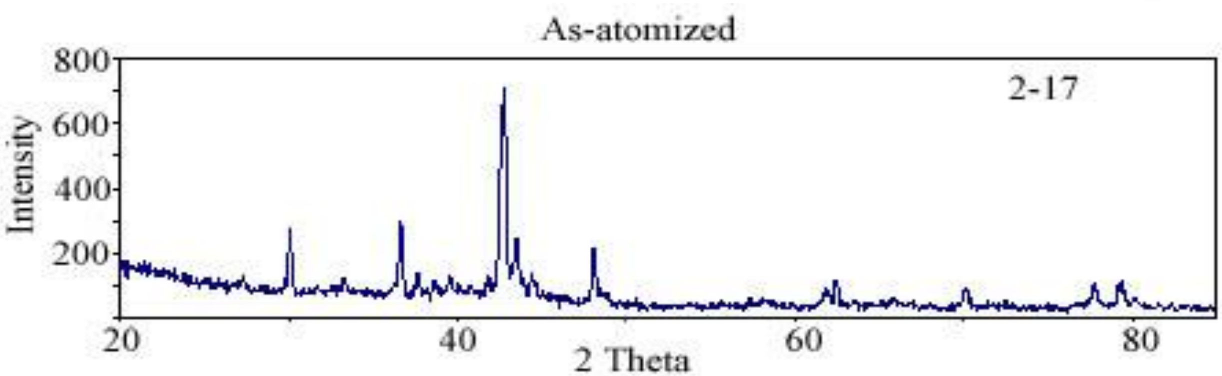
Identification of Solidification Pathway in Large Atomized Powder

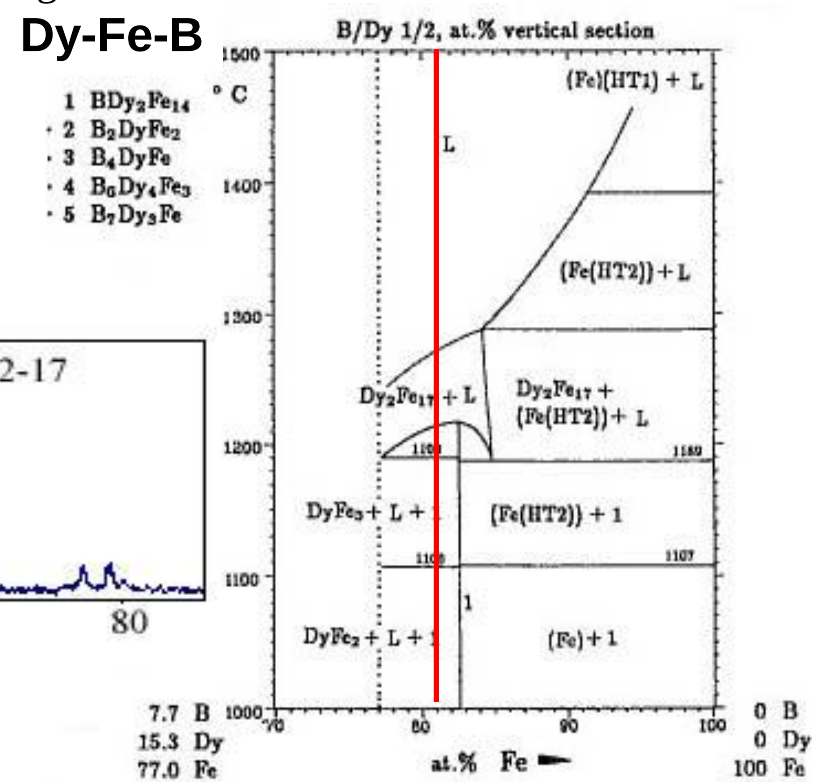
AMES LABORATORY



Hypothesis:

- Reduced undercooling of large powders promotes nucleation of 2-17 phase.
- 2-14-1 dendrites form in interior on further cooling.

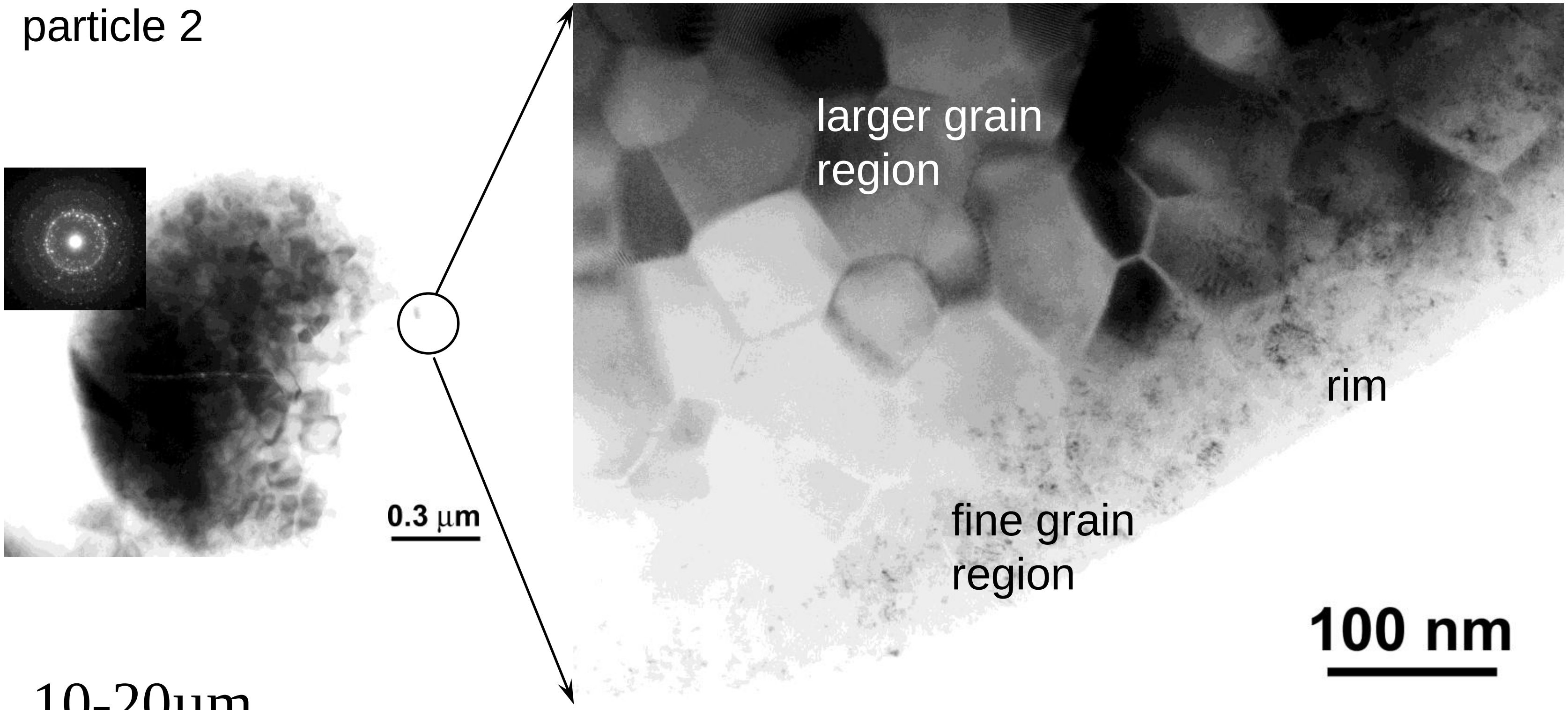




TEM of Gas Atomized Spherical Powder $(Y_{0.5}Dy_{0.5})_2Fe_{14}B$ (BT-4-204)

AMES LABORATORY

particle 2

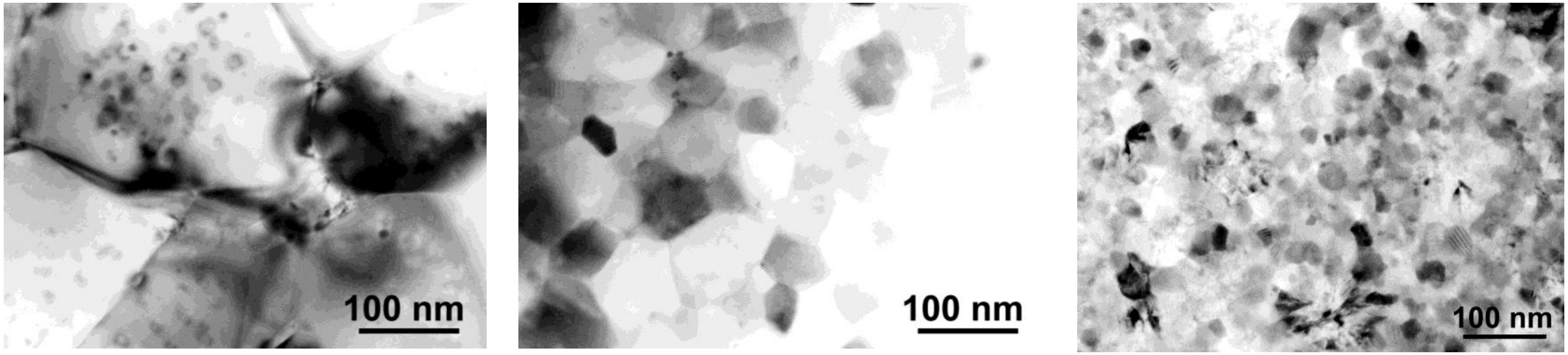


10-20µm

Zr-Substitution Effect on As-Solidified Ribbon Microstructure

AMES LABORATORY

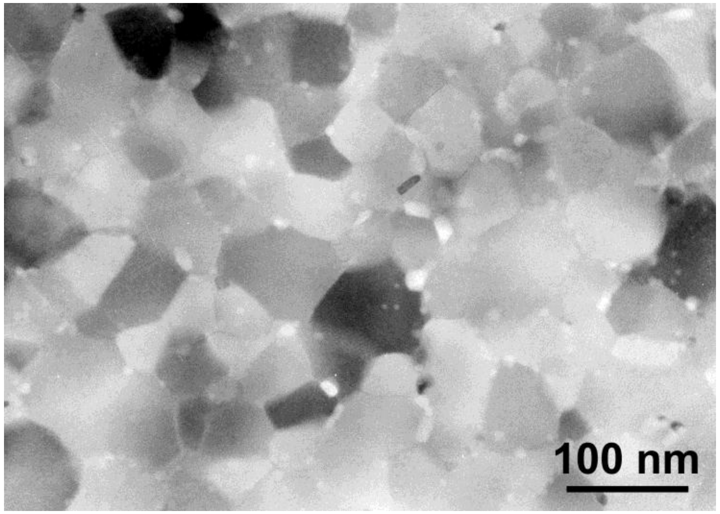
$[Nd_{0.5}(YDy)_{0.25}]_{2.2-x}Zr_xCo_{1.5}Fe_{12.5}B$ ribbons, 10 m/s, as-spun



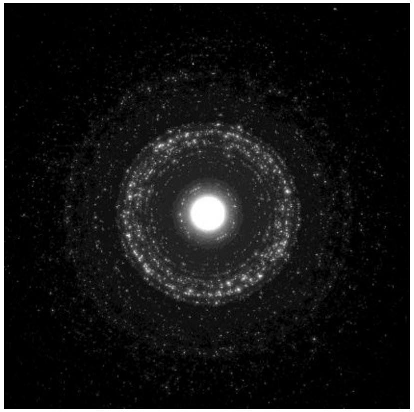
- **The average grain size is 200, 65 and 50 nm with x=0, 0.4, and 0.7, respectively.**
- **The sample with Zr of x=0.4 exhibits a uniform distribution of grains, indicating that the substitution of Zr can inhibit grain growth.**

TiC Precipitates after 800C, 15 minutes $\{[Nd_{0.45}(Y_2Dy_1)_{1/3*0.55}]_{2.15/17.15}Co_{1.5/17.15}Fe_{12.5/17.15}B_{1/17.15}\}_{1-2x}+Ti_xC_x$, x=0.02

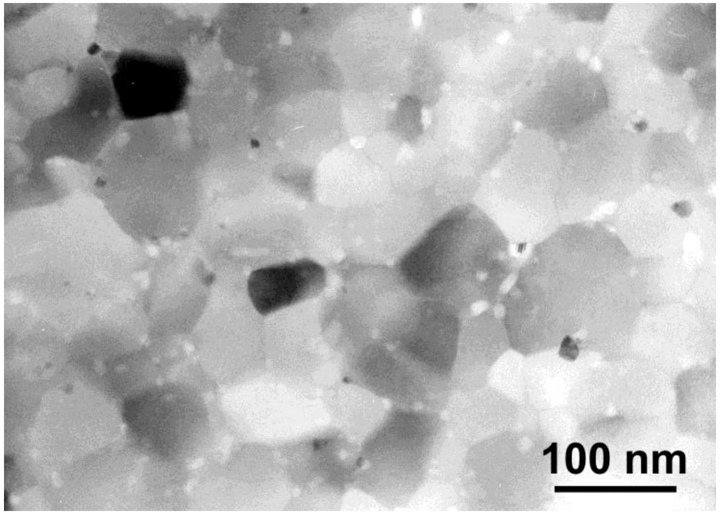
AMES LABORATORY



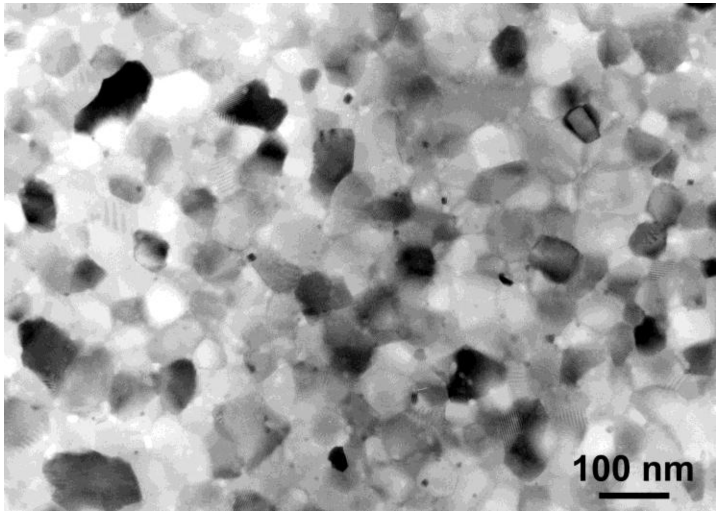
1965



1957

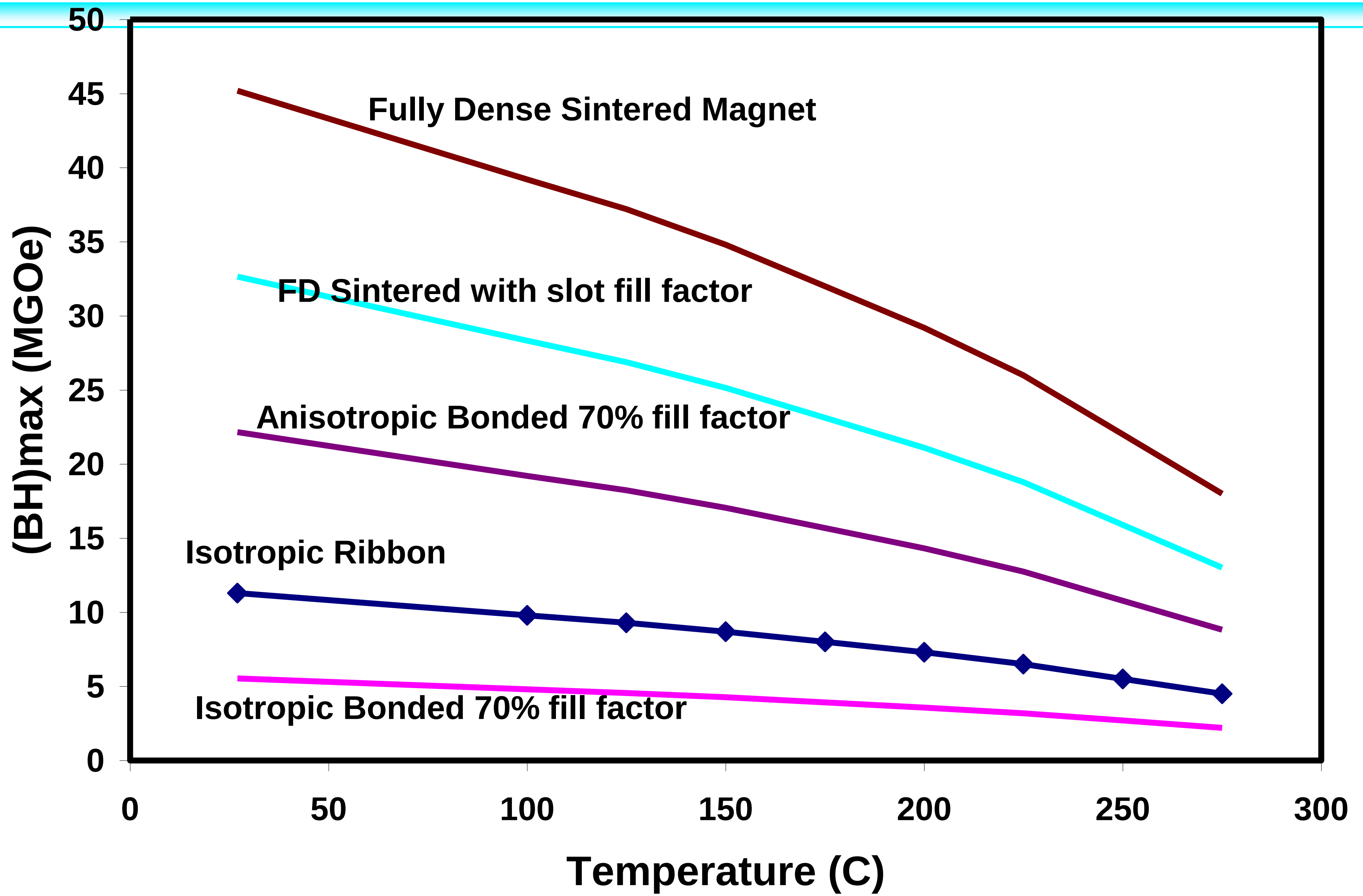


1966



1968

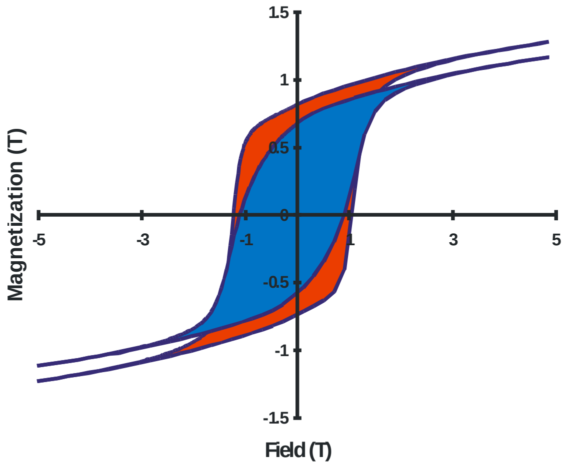
Estimated alloy performance



Ames Laboratory's FY07 Progress Update
Magnet Alloy Design

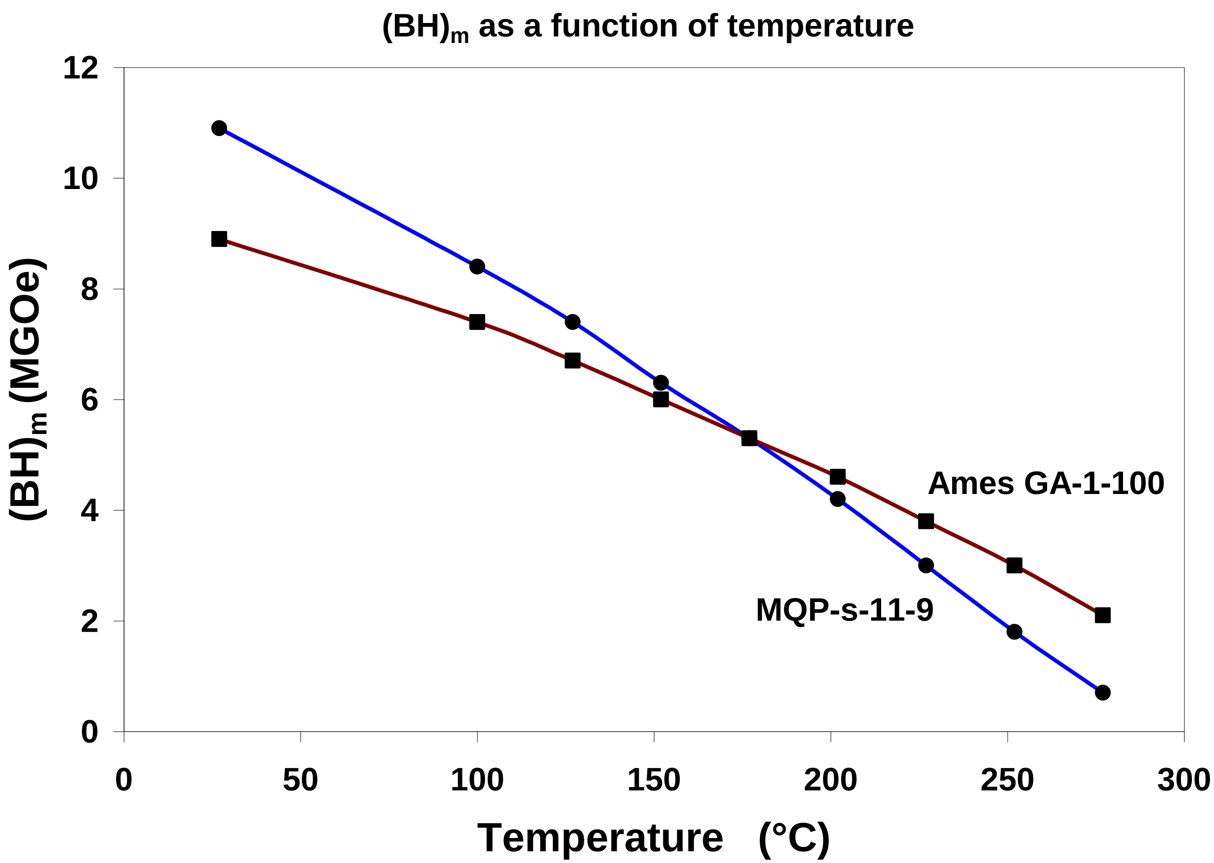
AMES LABORATORY

- Gas atomization
  - Benefits
    - Spherical powder
  - Barriers
    - Low quench rates
    - Must promote enhanced crystallization throughout the droplets
      - Focused on alloys with small additions of Zr and substitutions of ZrC for TiC
      - Developed alloy with optimized Zr + ZrC content
  - Status
    - magnetic properties of GA-1-100 powder:
      - 7 MGOe and 10kOe,
      - retained low temperature coefficients
    - achieved over a large range of particle sizes
    - compared to the best commercial spherical powder
      - improved coercivity,
      - nearly the same energy product at room temperature
      - Improved energy product above about 100 C
      - significantly improved temperature coefficients.
    - **Significant room for improvement remains**



Spherical Powder Energy Product vs. Temperature Comparison

AMES LABORATORY



Lower cross-over temperature

MQP-s-11-9 Spherical power from Magnequench International