New and Modified Alloy Powder Core Materials

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MAGNETICS®

Powder Core Alloy Types

Type	Composition	Primary Applications	μ_e Range
Iron Powder	Fe (or Fe & Si)	Power	14 – 90
Carbonyl Iron Powder	Fe	RF and High Q	4 – 35
Molypermalloy Powder (MPP)	80% Ni, 20% Fe	Power and High Q	14 – 300
High Flux	50% Ni, 50% Fe	Power	14 – 160
Sendust	Fe, Si, Al	Power	14 – 125
6.5% Silicon Iron	Fe, 6.5% Si	Power	14 – 90

Why aren’t there more alloy possibilities?

- The ferromagnetic elements available to work with are Iron, Nickel, and Cobalt.
- Cobalt is expensive (high saturation induction, but also high eddy current losses.)
- There are some known alloying sweet spots, and blending that is possible.
- But at the root, the magnetic action is performed by iron, or iron with nickel. The properties of those elements are a fundamental constraint.

Permalloy (81%) Sweet Spot

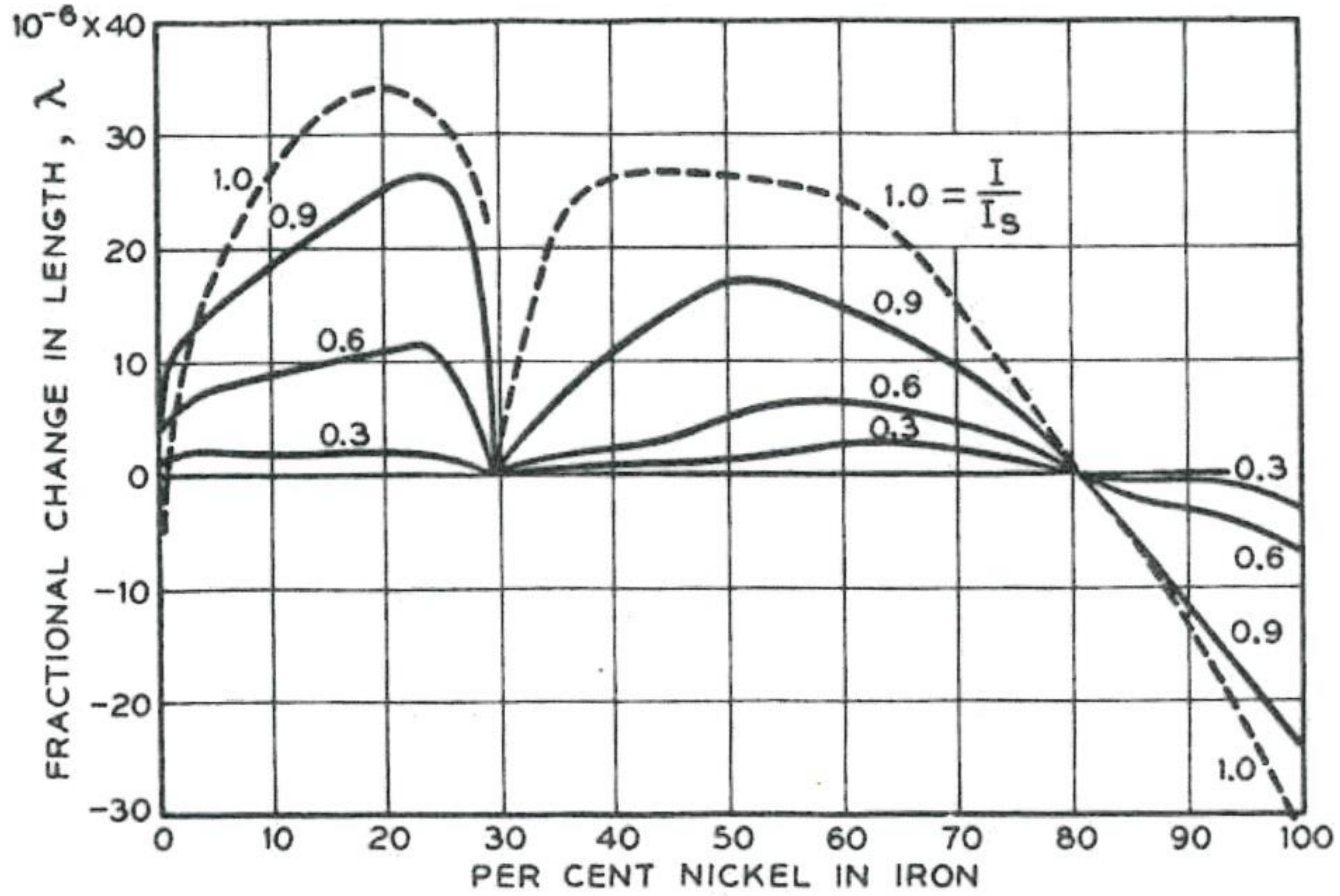
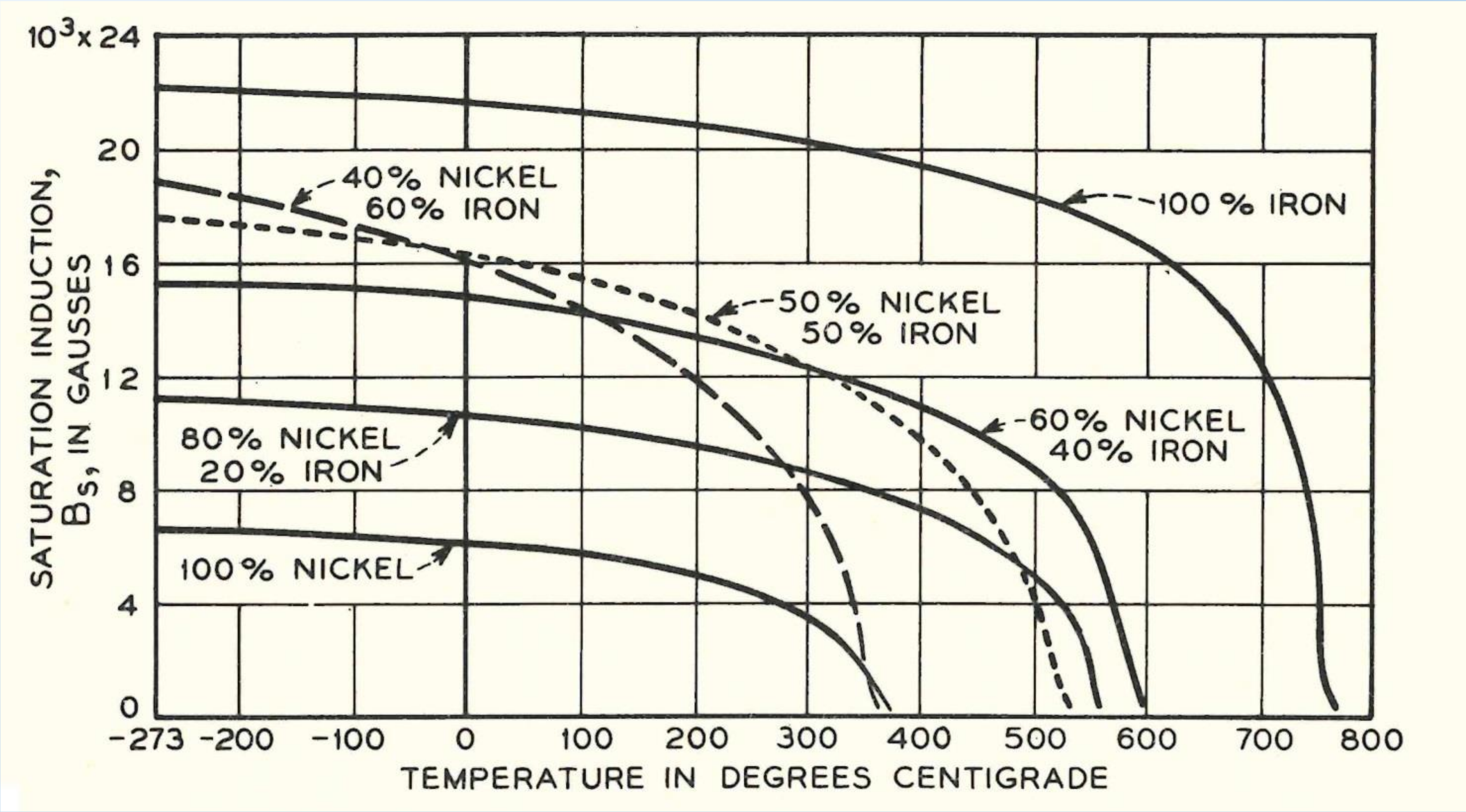


FIG. 13–98. Magnetostriction of iron-nickel alloys at various fractions of saturation.

Bozorth, Ferromagnetism

High Flux (50/50) Sweet Spot

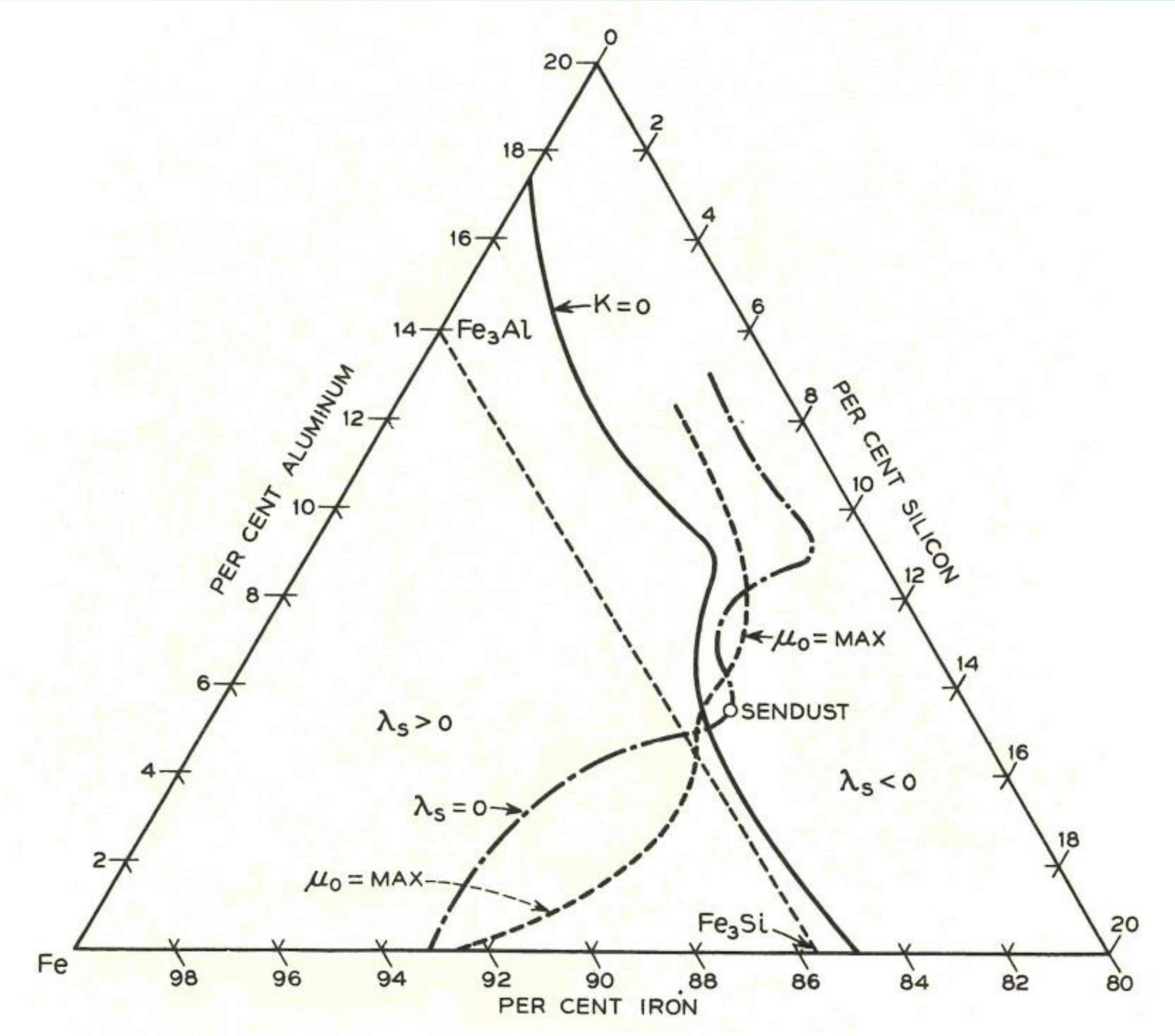


Bozorth, Ferromagnetism

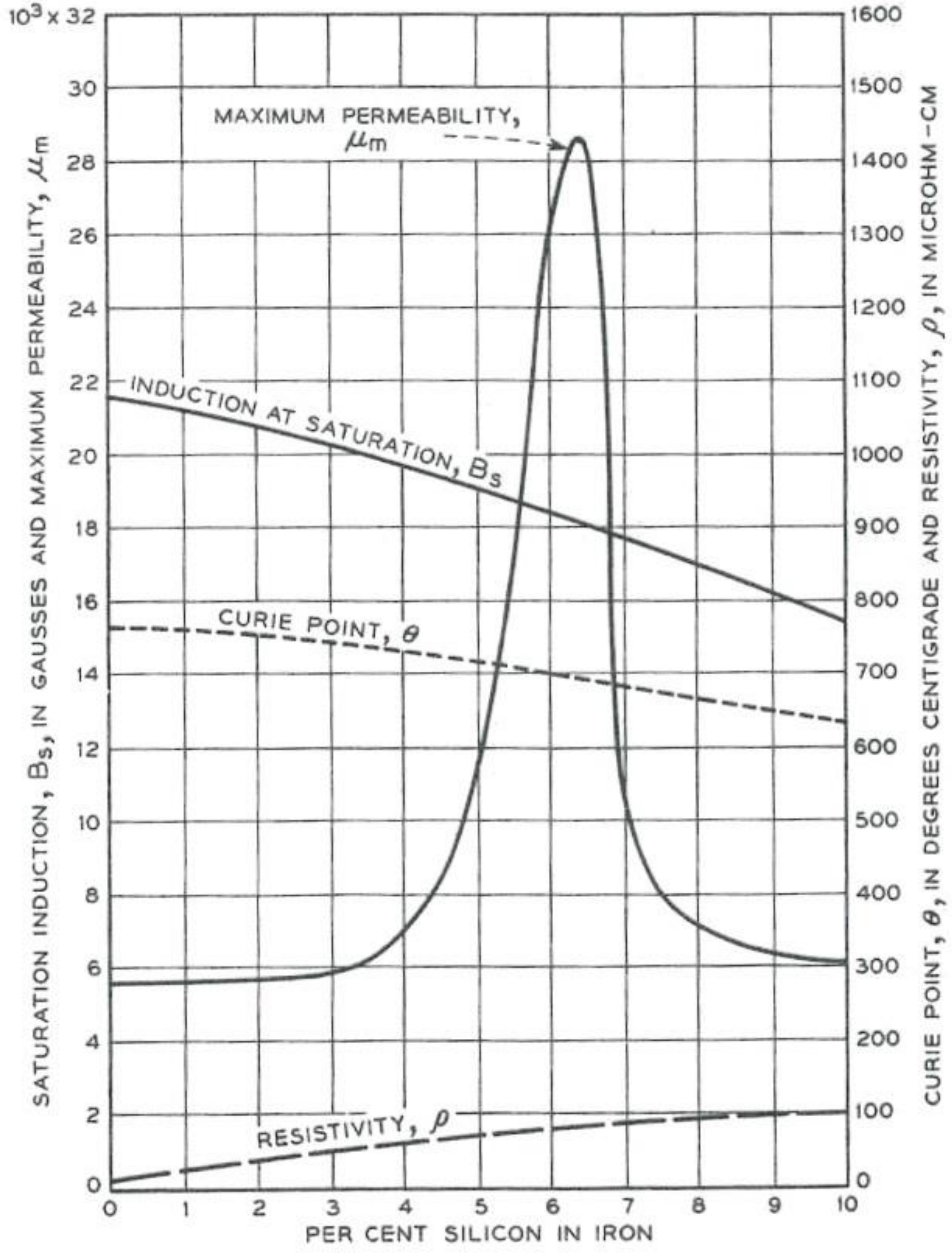
Non-magnetic alloying

- Silicon and Aluminum in Sendust to reach a minimum loss / maximum perm point.
- Silicon in iron to decrease losses and improve permeability.
- Molybdenum in Permalloy to decrease losses and increase permeability and responsiveness to annealing.
- Non-magnetic additions always sacrifice saturation induction (flux capacity).

Sendust Alloy Sweet Spot



Bozorth, Ferromagnetism



6.5% Silicon Iron Sweet Spot

Bozorth, Ferromagnetism

Blending

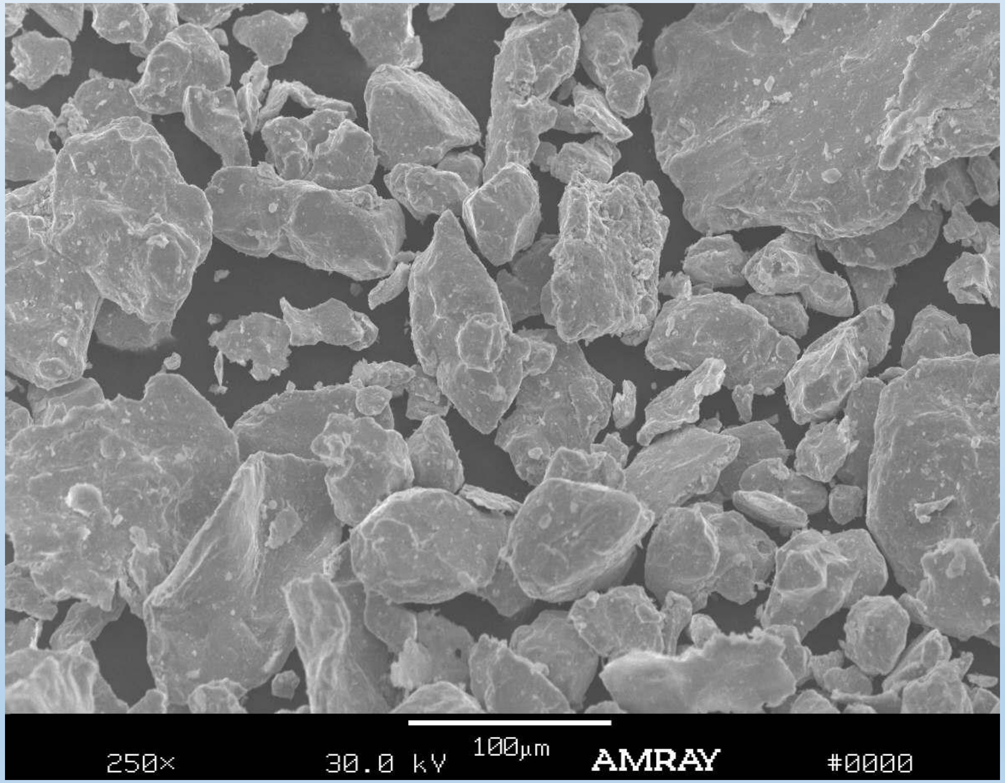
- Powder blends give intermediate performance for permeability, saturation, and losses.
- Blending can be useful for:
  - Fine tuning a material’s performance
  - Decreasing overall cost (in trade for some performance)
  - Making a powder better to work with, especially at pressing
  - Arriving at a target particle size distribution

Strategies for New Powder Core Materials

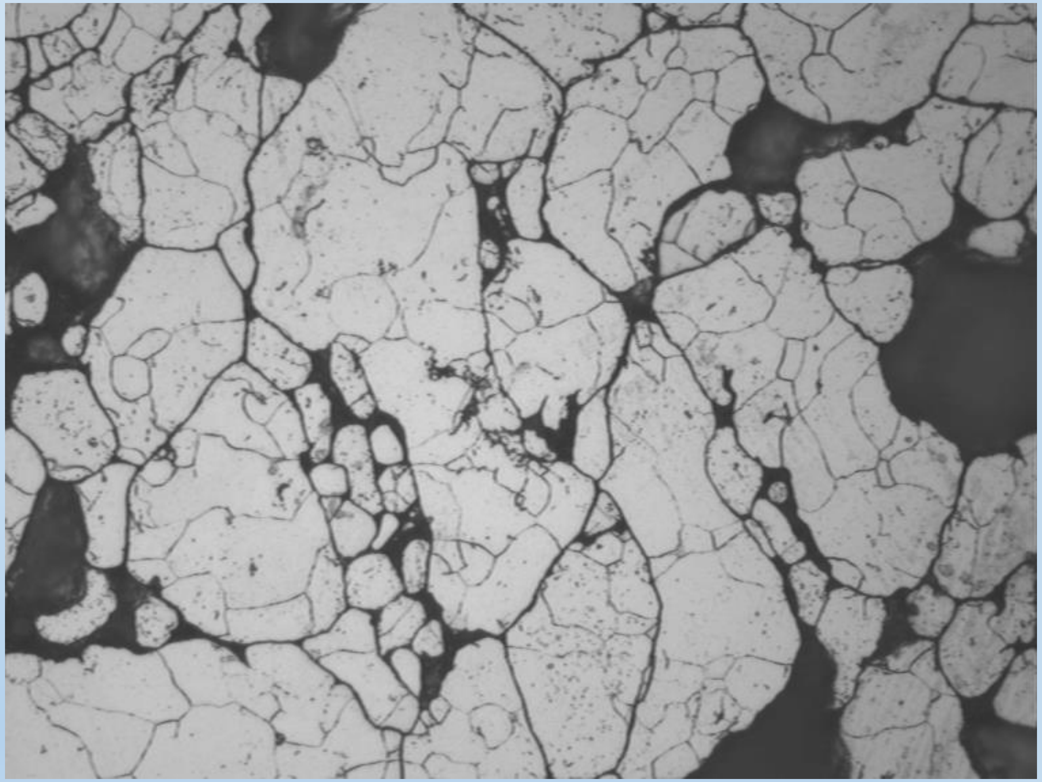
- Tailoring particle size distribution (PSD)
  - Finer grain sizes for lower loss at high frequency
  - Narrower PSD for more consistency
  - Coarser size or broader PSD for lower cost
- Alloy adjustments for performance fine tuning
- Modified insulation (distributed gap material)
- Blending
- Magnetic anneal or stress relief anneal adjustments
- Any of the above for pressing into new shapes

PSD and Insulation

Powder design affects not only the final core microstructure, but also the process for making cores.



Uncompacted Powder



Core Section

Process Notes

- There is a manufacturing feedback loop. The target inductance (perm) is a function of PSD and pressing density, and the upstream insulation process has to be correct if final core inductance is going to be correct.

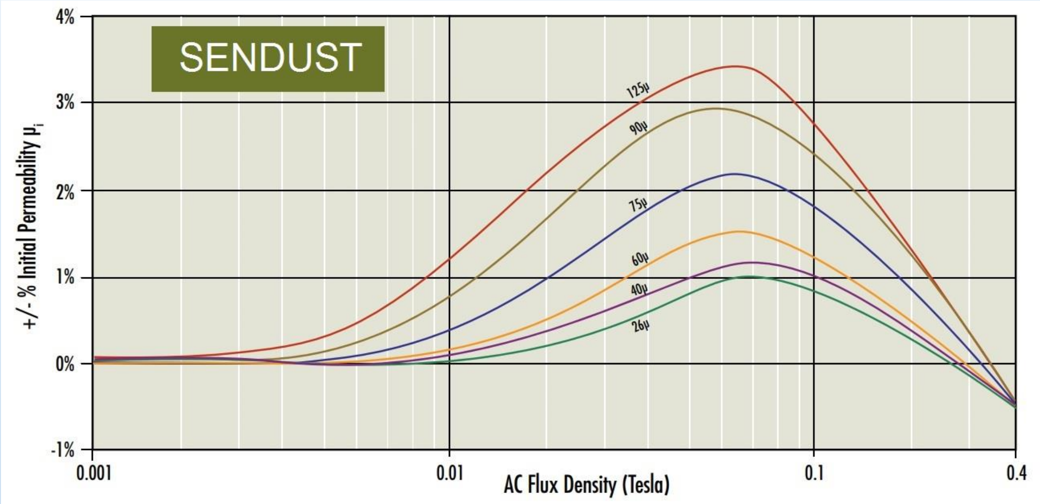
- B_{sat} is not destiny. E.g., MPP is 25% lower in alloy saturation than Kool Mμ, but significantly higher in DC Bias performance. Because multiple factors drive DC Bias performance.

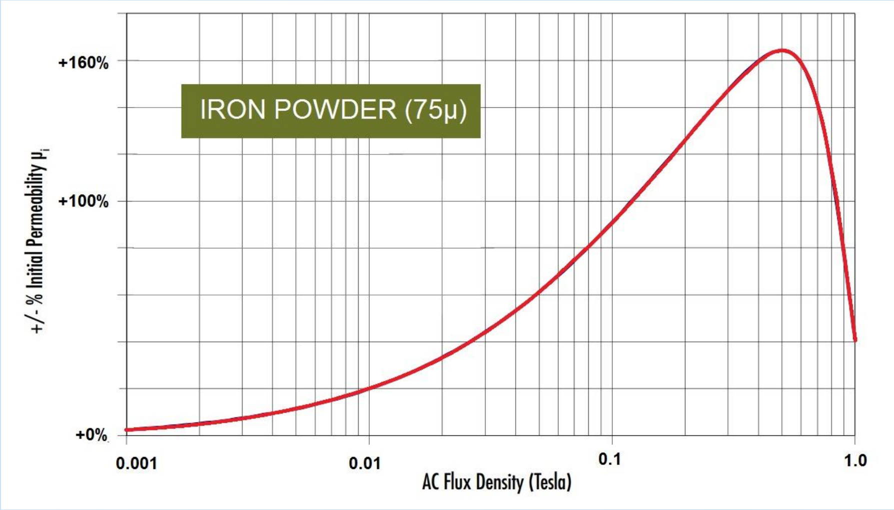
- Method of atomization; sieving; and insulation system are all critical elements.

- For lower alloy permeability, average insulation is thinner to reach the same effective perm. MPP can be built to 300μ, whereas 6.5% SiFe and iron powders reach only 75μ or 90μ.

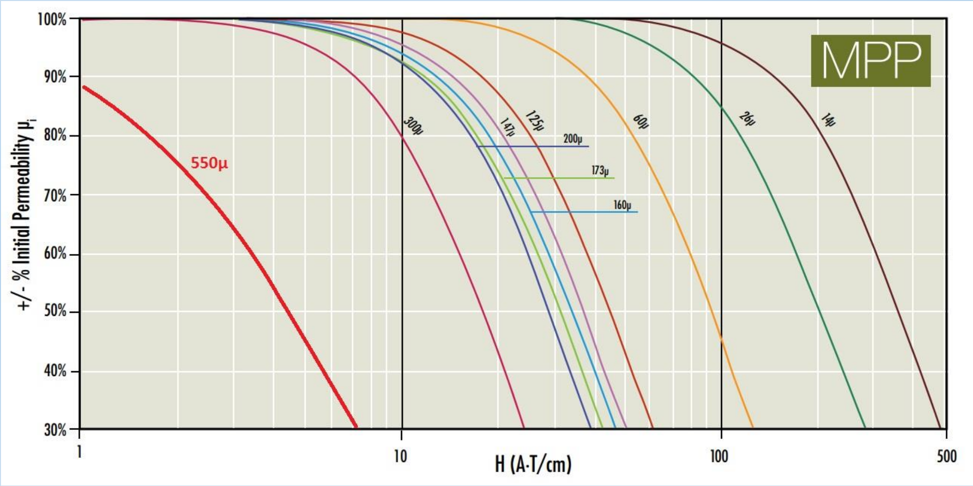
Alloy µ and effective µ

Because of the higher native alloy perm, µ vs. AC flux density is flatter for MPP and Sendust than for iron powders.





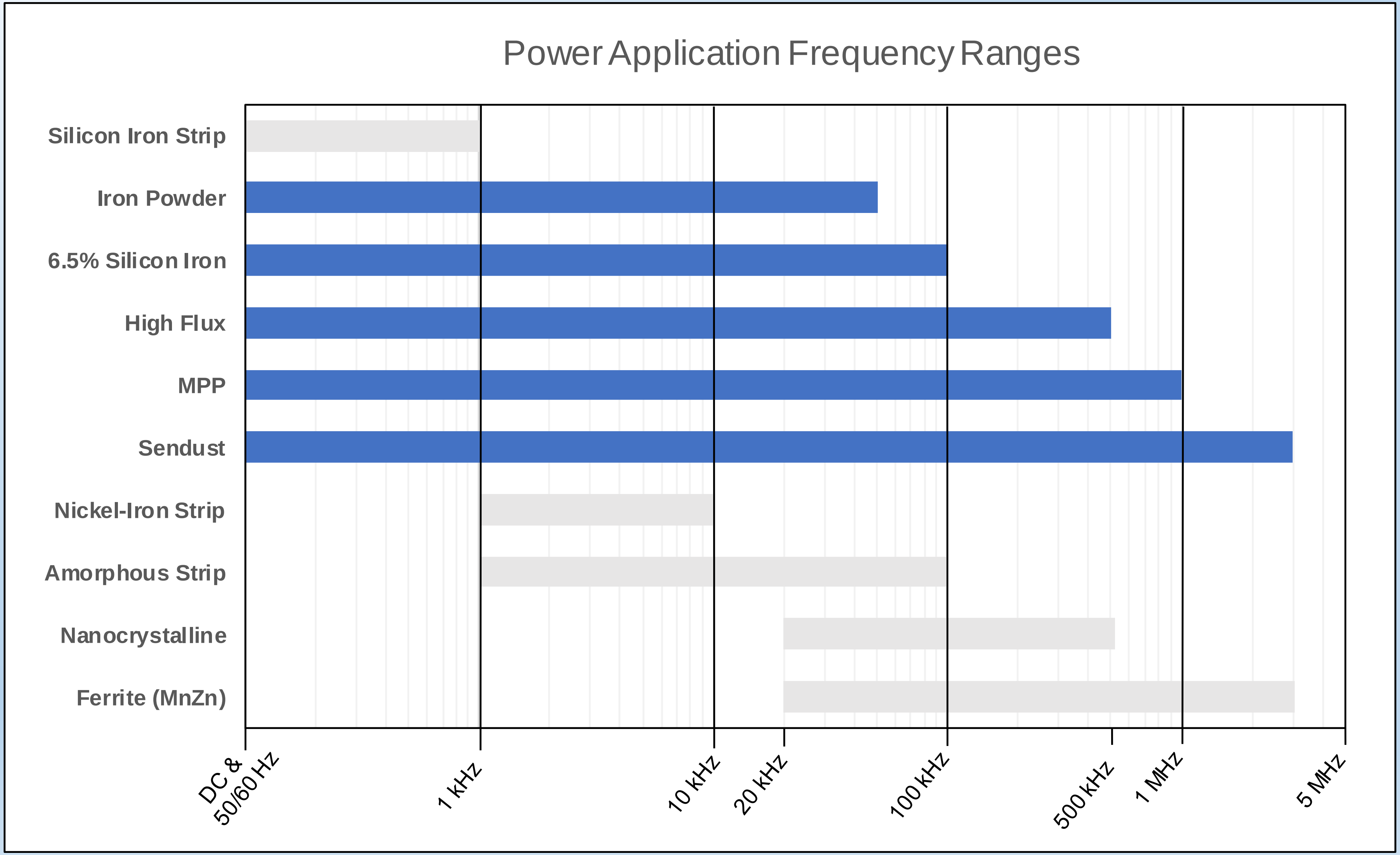
There is a 550µ variety of MPP possible, but only with special handling. 300µ is the practical limit for normal powder and realistic insulation.



Process Options

- There are two types of insulation.
    - Organic – lower in cost, easier and more flexible to press into large or complex shapes. But unable to survive post-pressing anneal.
    - High Temperature – permits anneal to relieve internal stresses after pressing. Allows high compaction pressures. Results in cores with high application temp ratings. But requires higher compaction pressures, is less flexible and is higher in cost.
- Powdering amorphous metals
    - Shares many of the same process elements
    - Plus additional costs and complexities

Alloy Families – Power



Commercial Materials by Family

Alphabetical Order

Iron Powder	MPP	High Flux	Sendust	Sendust +	6.5% Silicon	Blend
Best Cost	Best Loss	Best DC Bias	Low Loss & Low Cost	Higher Performance Sendust	High DC Bias & Moderate cost	Targeted Performance
Mix -18 Mix -26 Mix -52	MPP (CM) MPP (KM) MPP (MP) MPP (55)	High Flux (CH) High Flux (KH) High Flux (58) High Flux (59) Hi-Flux (HF)	Kool Mμ (77) KS KS-HF KW NPS NPU PPI Sendust (CS) Super MSS (MS)	Fine Flux (CF) High Frequency (SH) HP Kool Mμ Max (79) NPA NPH NPH-L Optilloy (OP) UltraFlux (U)	Fluxsan (FS) MegaFlux (CK) KSF NPF NPF-C NPI PowerFlux (W) XFlux (78)	HS KAH KAM KH KS NeuFlux (KNF) 73 75

Target Applications

- GaN and SiC (losses characterized at 200-500 kHz)
- Future high frequency (losses characterized up to 1-3 MHz)
- Low frequency / high current (e.g. UPS at <20 kHz, >50 KVA)
- Cost-sensitive projects
- Non-toroids
  - Round center leg E / planar
  - Picture frame structures
  - Blocks and cylinders