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Sandia National Laboratories

Additive Manufacturing of Functionally Graded Soft Magnetic Alloys

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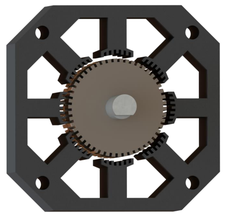
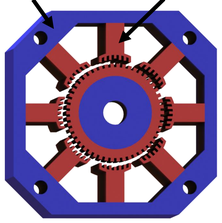
Motivation: Simultaneously improve mechanical and magnetic properties through spatial control of material chemistry

NEMA-17 Motor



Rotor and stator

Lightweight High saturation

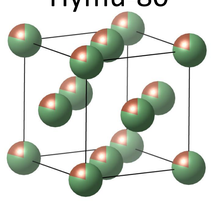


Multimaterial motor design

Graded soft magnets may enable
1) Weight reduction
2) Increased efficiency
3) High temperature operation

Materials of interest

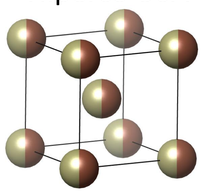
Hymu-80



80Ni-16Fe-4Mo
High Permeability
Decent Ductility

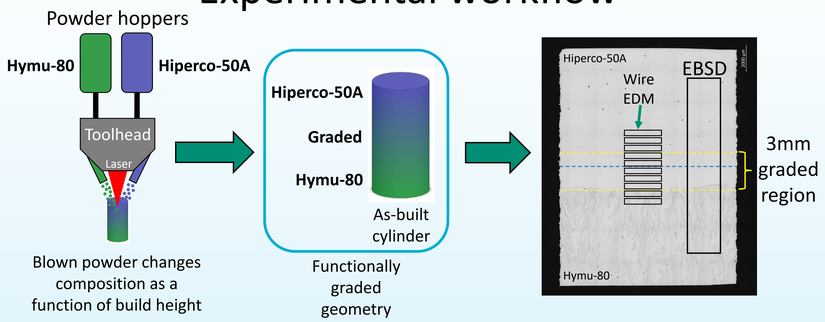
Grading

Hiperco-50A



49Fe-49Co-2V
High Saturation
Very Brittle

Experimental workflow



Microstructure of Graded Samples

EBSD phase map shows transition from FCC to BCC

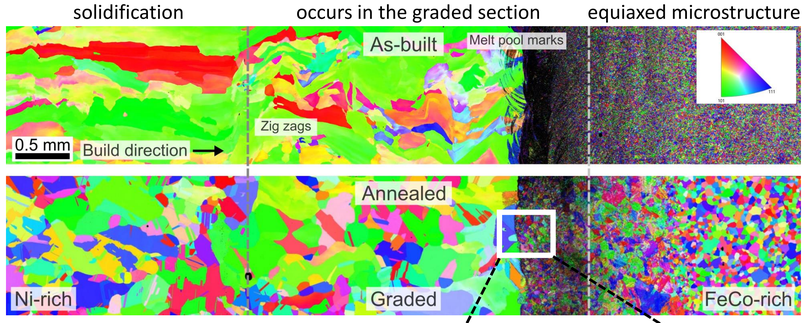
- Hiperco-50A is more soluble in Hymu-80
- 2-phase region is relatively narrow

EBSD inverse pole figure map highlights grain structure

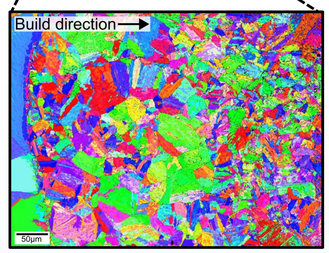
Columnar microstructure forms due to epitaxial solidification

Sharp transition between crystal structure and microstructures occurs in the graded section

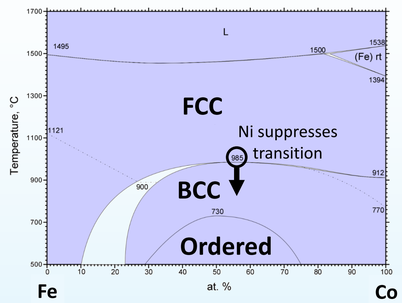
Rapid solidification causes a refined equiaxed microstructure



- Annealing Ni-rich side causes recrystallization into lower-aspect ratio grain structure
- Martensitic microstructure appears in graded section due to Ni in the BCC structure
- FeCo-rich grains grow due to thermal treatment



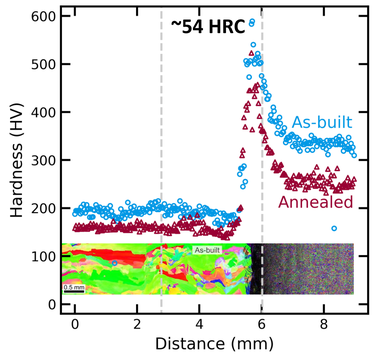
Refined microstructure shows presence of martensite



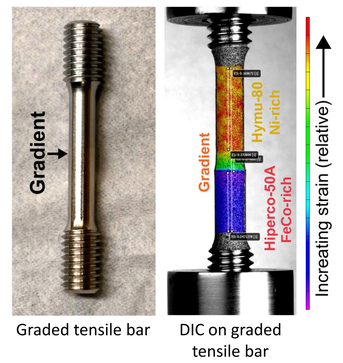
Fe-Co phase diagram highlighting phase transitions

- Formation of martensite occurs isothermally in Fe-Ni alloys
- Ni suppresses FCC-BCC transition temperature
- BCC grains have less time to coarsen before material is fully cooled

Grading increases mechanical hardness

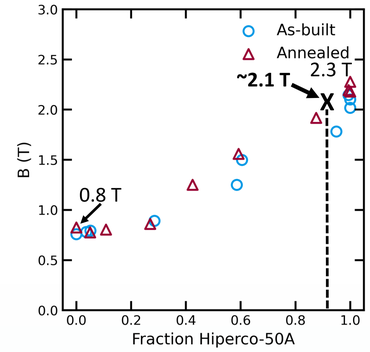


- Maximum hardness is aligned with refined microstructure
- Alloy chemistry shows little influence on hardness



- Hymu-80 has greatest relative strain
- Hiperco-50A exhibits low strain
- Tensile bars broke in the grips, preventing further analysis

Magnetic saturation follows mixing rules



- **Grading improves the hardness by nearly 2x with only a 10% reduction in magnetic saturation**
- Saturation of endmembers shows expected values with 0.8 T for Hymu-80 and 2.3 T for Hiperco-50A
- Magnetic saturation trends linearly as a function of composition, suggesting microstructure has little influence

Summary

- Graded soft magnets can be formed by AM processes
- Ni addition to FeCo alloy forms a refined martensitic microstructure
- Refined microstructure improves hardness without major detriment to the magnetic properties

Future work

- In-depth alloy chemistry study on the refined region
- Characterize mechanical, magnetic, and electrical properties of the alloy

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