Substituting zinc for iron in neodymium-iron-boron ($Nd_2Fe_{14}B$) magnets

Kimberly Kult[1], Patrick Donovan[2], W. Tang, K.W. Dennis, and R.W. McCallum[3]

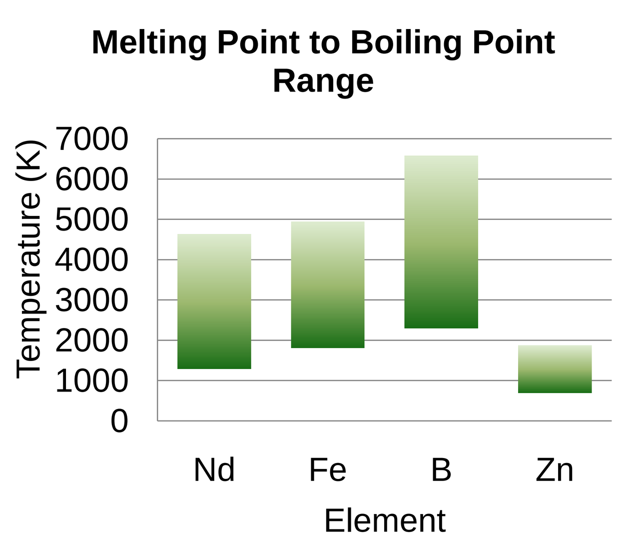
[1]North Polk Schools [2]South Hamilton Schools [3]Ames Laboratory

Background and Motivation

Permanent magnets are key components in modern technology. They are used in many electronic devices such as CD and DVD players, MP3 players, cell phones, digital cameras, watches, and speakers, as well as in drive motors for electric and hybrid vehicles.

An alloy of neodymium, iron, and boron ($Nd_2Fe_{14}B$) is the best currently available permanent magnet material. Altering the $Nd_2Fe_{14}B$ material could produce a magnet with enhanced properties, such as operation at higher temperatures. Automakers have expressed that future electric drive motors will need to operate at temperatures up to 200°C.

Substituting zinc (Zn) for some of the iron (Fe) may enhance the magnetic properties. However, it is not as easy as melting the metals together. The boiling point of Zn is below the melting point of Nd, Fe, and B, making the alloy difficult to create.



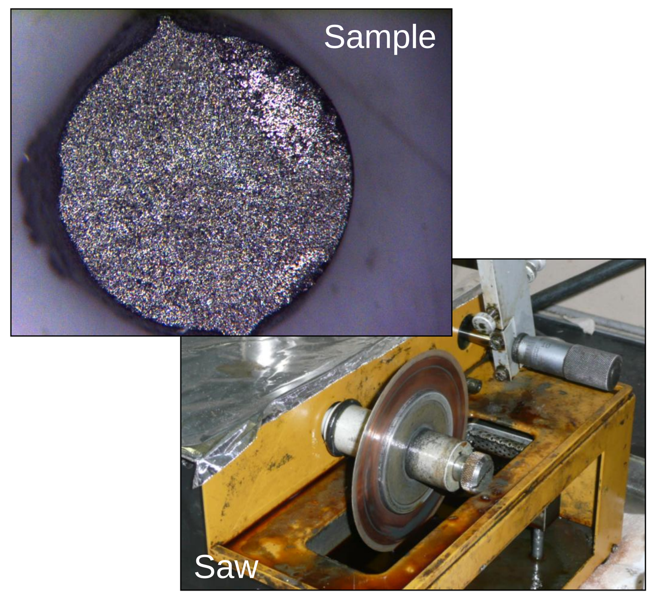
It may be possible to substitute some Zn for the Fe using a two-zone furnace to control the vapor pressure of zinc. This experiment was an attempt to make $Nd_2Fe_{14-x}Zn_xB$, using 5 values of x (0.0, 0.5, 1.0, 1.5, 2.0) and testing zinc diffusion at 4 different reaction temperatures (1000°C, 1050°C, 1100°C, and 1150°C).

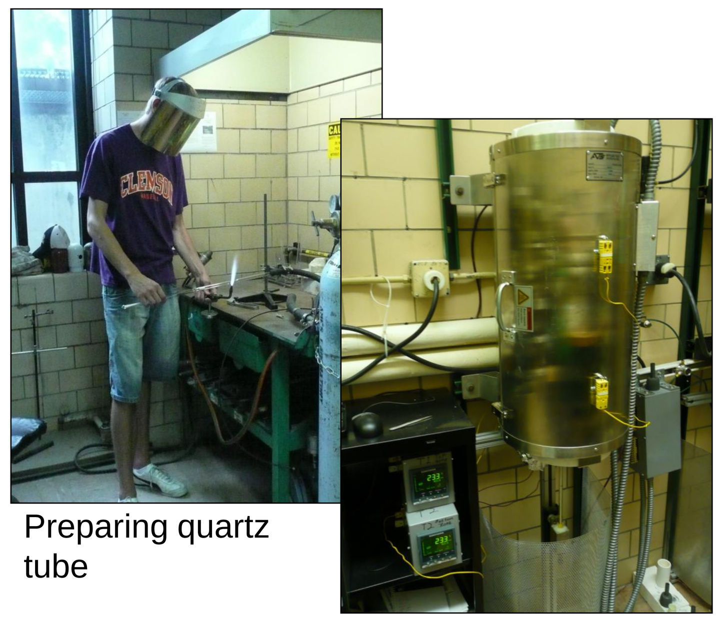
The samples will then be analyzed by magnetization, thermal analysis, and scanning electron microscopy.

Materials and Methods

Five compositions were prepared by pouring molten alloy into a copper mold, followed by heat treatment of 1000°C for 65 hours. The resulting ingots were a combination of $Nd_2Fe_{14}B$, pure Nd, and $NdFe_4B_4$, determined by the calculated iron deficiency.

Samples for experimentation were cut using a diamond saw. The amount of zinc to add to each sample was calculated based on stoichiometry.





Preparing quartz tube

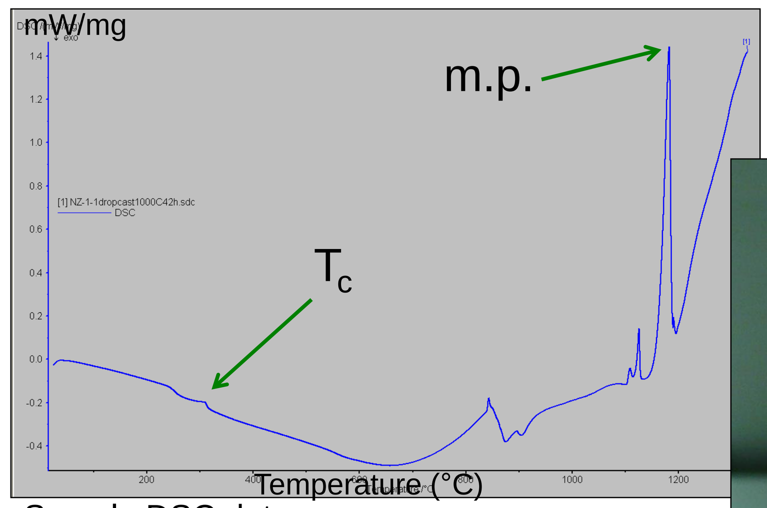
Furnace

Quartz tubes were designed to separate the zinc from the sample, allowing two temperature zones to be used – a lower temperature zone determining the zinc vapor pressure and a higher temperature for diffusion into the sample.

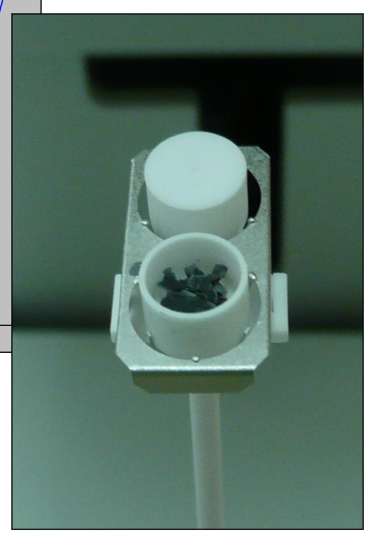
Following the 42-hour reaction in the two-zone furnace, the samples were air quenched and then analyzed by thermal analysis, magnetization, and scanning electron microscopy.

Differential Scanning Calorimetry (DSC)

The DSC is an apparatus used to study what happens to materials as they are heated, and identifies phases changes and a Curie temperature (T_c), the critical temperature at which magnetization drops.



Sample DSC data



Sample in DSC

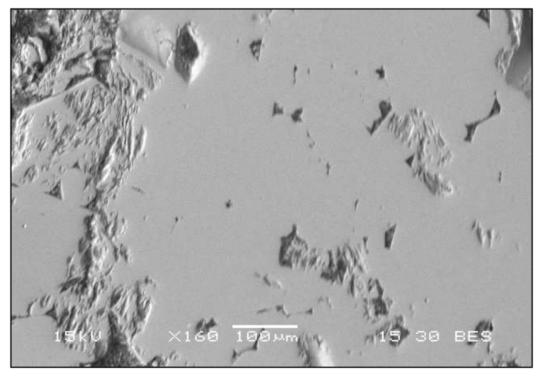
SQUID

Superconducting Quantum Interference Device magnetometer (SQUID)

The SQUID measures magnetic properties and was used to inform us if magnetization changed with the addition of zinc.

Scanning Electron Microscope (SEM)

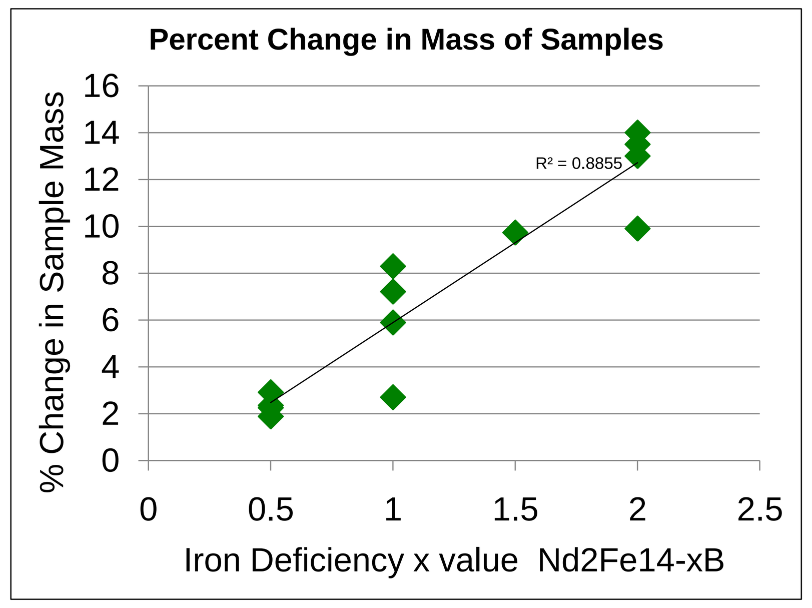
Energy dispersive spectroscopy (EDS) was used to determine the elemental composition of the samples, to identify whether zinc was present.



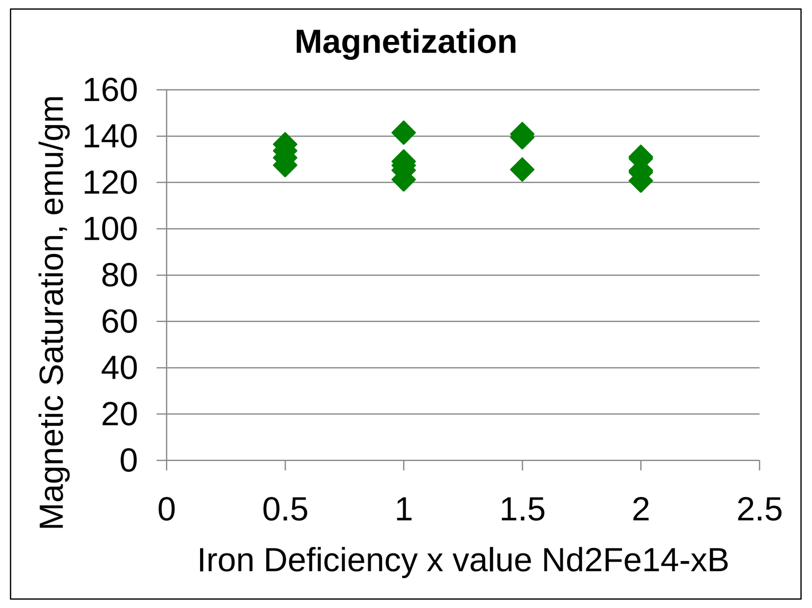
SEM image

Results

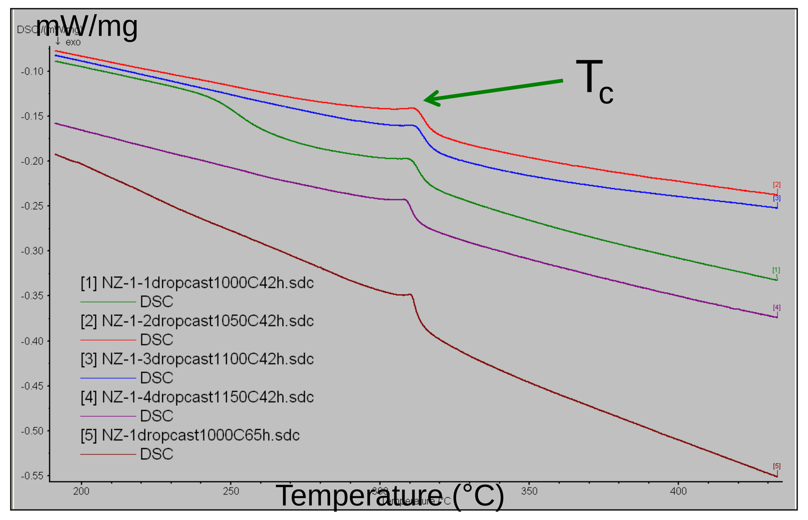
Increases in mass for all samples indicate that some zinc went into the samples. The trend line shows a higher integration of zinc in the more iron-deficient samples.



Data obtained from SQUID analysis demonstrates no significant effects from added zinc on saturation magnetization of the ferromagnetic sample.



Data from DSC shows no significant change in the Curie temperature.



SEM analysis confirmed the uniform presence of zinc, but it was not a full reaction, and some additional compounds besides $Nd_2Fe_{14-x}Zn_xB$ were present.

Future Work

Future work on this project will include

- Investigating other possible reaction routes to add zinc to the alloy
- Additional x-ray diffraction data to determine if the crystal lattice size changed with zinc replacement
- Obtaining magnetization data at higher temperatures

Acknowledgements

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