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

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Introduction

$Nd_2Fe_{14}B$ permanent magnets are a part of everyday life. They are used in laptops, mp3 players, headphones, car seats, and computer hard drives. They are vital to the way we live today. The temperatures at which they are effective are too low for many of the purposes we have for them. By putting zinc into these magnets in place of some iron it is hoped that certain properties will improve including the strength of the magnet at higher temperatures.

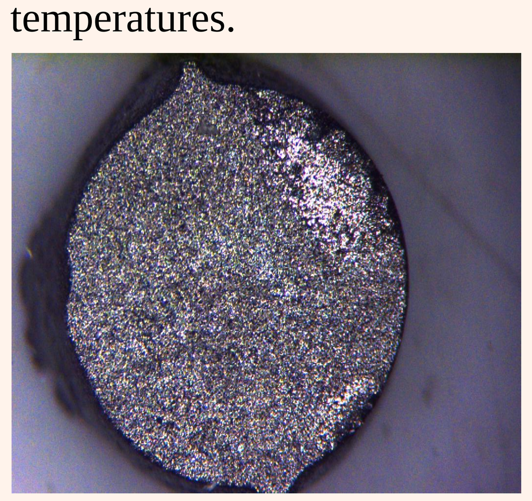
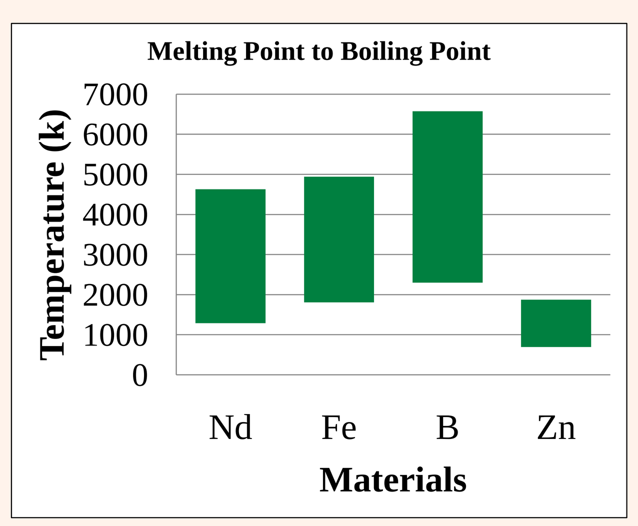


Fig. 1. Sample of NZ-4-2.

Problem

Placing zinc into $Nd_2Fe_{14}B$ is not as easy as just melting them all together and then cooling. Zinc becomes a gas at the temperatures at which iron and boron would melt. You just can't force zinc to go into the $Nd_2Fe_{14}B$ material.

Keeping the body of the zinc at a lower temperature while exposing the $Nd_2Fe_{14}B$ to a higher temperature should allow the zinc vapor to react and form a new material while controlling the zinc vapor pressure.



We are attempting 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) while maintaining the zinc at 800°C.

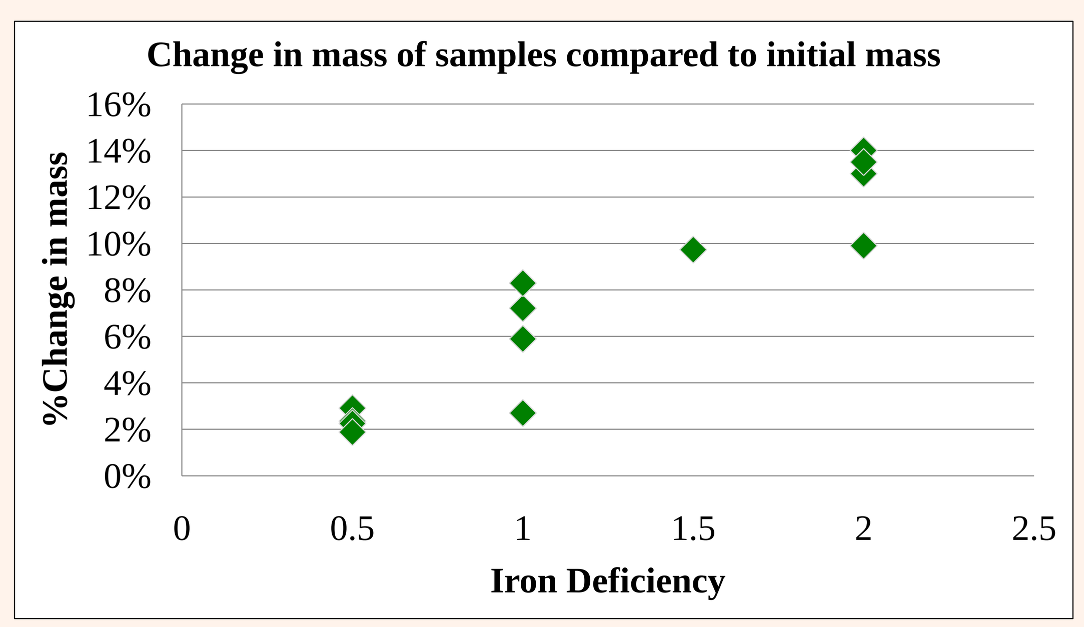
Procedure

•Form five compositions of the material by pouring molten alloy into a copper mold followed by heat treating at 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.
•Using a diamond saw blade, cut small cylinder samples for each of the 4 temperatures being tested and one control.
•Determine the mass each of the samples and predict the amount of zinc to be used up in the reaction and measure this out.

Procedure cont.
•Form a quartz tube that is 18 inches tall, 12 inches from the bottom to the neck and 6 inches from the neck to the top. Place the zinc at the bottom of the quartz tube and place the sample in an alumina crucible at the neck. Use a vacuum pump to remove the air and then fill with argon gas and seal the top.
•Place the quartz tube in the two zone furnace with the zinc near the bottom thermocouple and the sample near the upper thermocouple. Set the temperatures and let it run for 42 hours.
•After 42 hours, determine the mass of the sample and any remaining zinc if possible.
•Analyze the sample by using the DSC, SQUID, and SEM.

Results

Mass Change
Comparing the masses of the sample before and after the 42 hours in the furnace is easily done. Overall, all samples increased in mass noticeably. Since the samples were all different masses to begin with, it is helpful to compare the change in mass to the initial mass of the sample. The change in mass increases as the iron deficiency goes up due to added zinc mass.



DSC (Differential Scanning Calorimetry)
The DSC records the amount of heat necessary to increase the temperature of the sample and indicates temperatures of phase changes and the Curie temperature. The samples are placed into a small alumina crucible and the measurements of the sample are compared to a control cup.

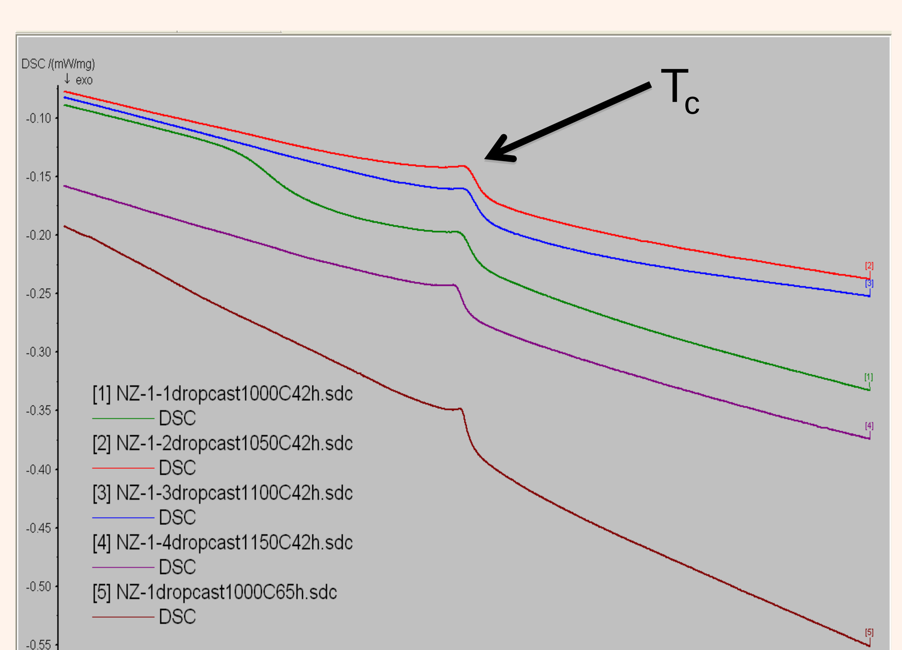
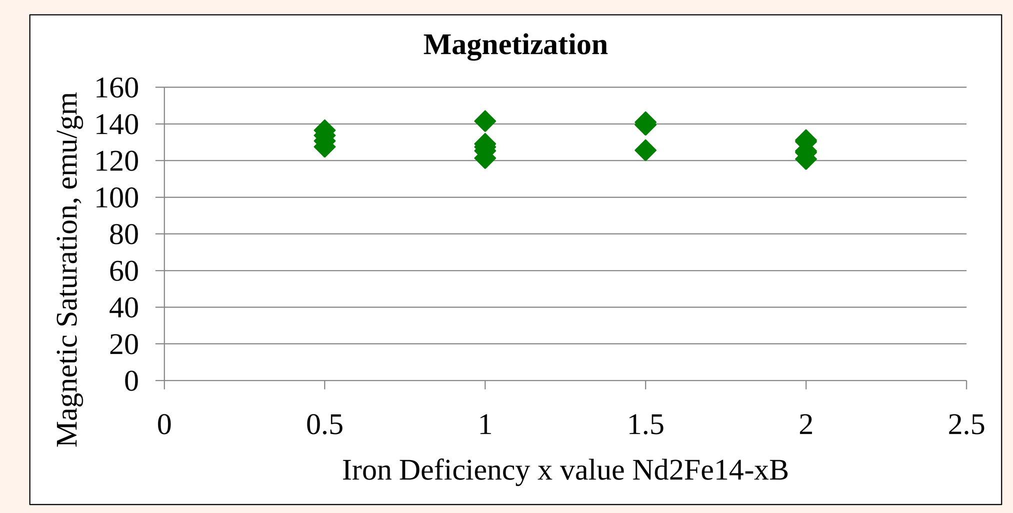


Fig. 2. DSC graph of sample NZ-1 series, mW/mg is the vertical axis and temperature in Celsius is the horizontal axis.

The results from the DSC showed no noticeable change in the Curie temperatures (T_c), the temperature at which magnetization drops, of the samples that had zinc added compared to the ones without zinc. The DSC also showed very similar decomposition points for the samples indicating that there wasn't a lot of change occurring from one sample to the next.

SQUID (Superconducting Quantum Interference Device)
The SQUID measures the initial magnetic saturation of the samples. Samples are placed into the SQUID and the magnetic properties of the sample as a function of the magnetic field being applied to it are calculated.



The measurements obtained from the SQUID shows no significant changes in initial magnetic saturation of the samples.

SEM (Scanning Electron Microscope)
The SEM is a type of electron microscope that images the surface by scanning it with a high-energy beam of electrons. The electrons cause X-rays to be produced and the energies of the X-rays can help identify the elements and the ratio of the elements present.

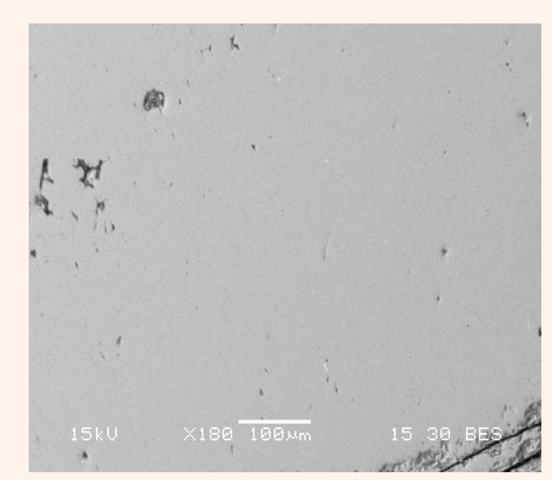


Fig. 3. Image of sample NZ-1-3 using SEM.

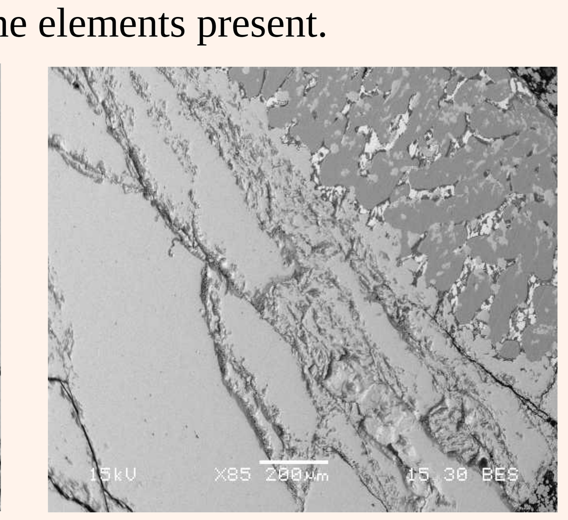
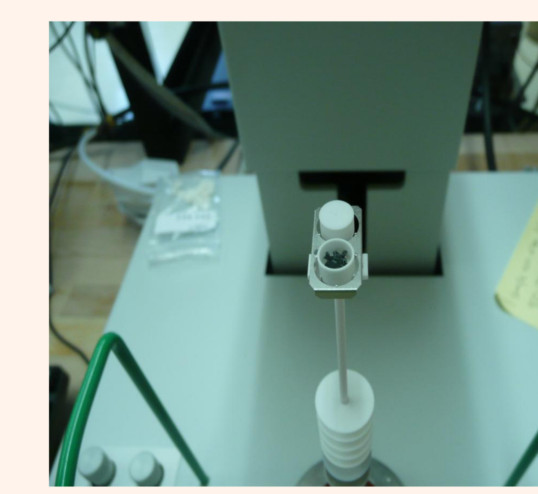


Fig. 4. Image of sample NZ-2-2 using SEM.

Of the samples analyzed using the SEM, the majority showed a uniform appearance which indicated that the zinc was reacting and mixing with the samples uniformly. The X-rays produced by the SEM showed that zinc was in the sample in lower concentrations than the levels initially predicted. One sample analyzed did show segregation of the materials indicating the zinc did not react uniformly with the sample but it happened to only 1 of 6 samples analyzed.



Conclusions

The big question is not just whether zinc is reacting with the NdFeB samples but how is it reacting. It seems pretty obvious by looking at the mass change and the results from the SEM that zinc is joining with the NdFeB samples. It is still uncertain exactly how the zinc is reacting and what new compounds are formed. It was hoped that the zinc would react and form an homogeneous sample but the zinc could have combined with the free neodymium or any one of a couple different ways.

Acknowledgments

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