The Disregarded Experiment

First let me thank Tony Morcos for pinch hitting for me in the summer issue of Magnetics Magazine. He made some very insightful comments about the use of permanent magnets in wind power applications. It is a good example of two concepts that I believe strongly 1) rare earth permanent magnets, as much as I love them, are not the only way to generate magnetic flux and 2) it is wrong to simply consider energy product and coercivity alone when selecting a magnet. We need to be smarter.

For this issue I wanted to discuss another topic that is also near and dear to me that arose innocently in a conversation I had in Chicago during Magnetics 2009 with Dr. Karl Gschneidner, the distinguished professor from Iowa State University. As we sat down for lunch, we were discussing a presentation on Y additions to NdFeB magnets we had just heard from Karl's colleague, Dr. Bill McCallum.[1] Bill's data showed that a partial substitution of Y for Dy was possible for rapidly quenched NdFeB, as a way to increase the coercivity and reduce its temperature coefficient. This is intriguing and potentially useful concept. One of the things that occurred to me as I listened to Bill was the idea that one consequence of replacing Dy with Y would likely make the magnet less dense. At least that is what I would expect to find since yttrium has a much lower density than dysprosium (4.47 g/cm^3 vs. 8.55 g/cm^3). For an industry obsessed with dollars per pound or flux per pound, this is a novel approach; keep the flux constant but reduce the weight of the magnet. It certainly might be appealing in a moving magnet application where the weight of the magnet becomes a major consideration. But beyond that idea, an even lower density magnet is possible with another rare earth, prompting my question, "Have you considered scandium?" Karl said no, the price of scandium meant that they would not consider it. This brings up an interesting point about materials research. Just for comparison to the other two materials, scandium has a density of 2.99 g/cm^3.

Unlike the speed of light, pi or Planck's constant, rare earth prices are not fixed by nature; they are fixed by man. Those of us who have been around the rare earth business for a while know that the price of any individual rare earth fluctuates over time due to the complex interplay of supply and demand. Rare earth prices are anything but fixed; in fact several organizations follow their prices. So to ignore a possible substitution because of today's price is to overlook potentially fertile ground.

But to Karl's point, scandium metal *is* expensive. The first 100 grams to make a sample melt might cost in the neighborhood of $1,000. That is enough to buy several kilograms of terbium, dysprosium or yttrium. Over time scandium has remained relatively expensive compared to most of the other rare earths. However, that has not stopped scandium from finding several viable commercial applications. For example, an alloy of aluminum containing 2% scandium is a very popular choice for baseball bats and other sporting applications.[2] If nothing else, this example should teach us that we should not ignore the possibility of using scandium in a commercial product as an additive simply because it is expensive.

The high cost of a relatively minor alloy ingredient is really is not important as one might think in materials research or, at least, it should not be. The main purpose of scientific research is not to find the cheapest materials at the outset of a project. First and foremost, research needs to find alloys with desirable or unusual properties, regardless of material costs. Knowledge should trump cost. At this stage it is more important to be thorough. This is especially true for the rare earths, a series of very similar elements with a wide variety of properties. All alloy possibilities should be considered at the beginning, something we learned in the development of both SmCo and NdFeB magnets. The reason for the preliminary exploration is to isolate the feasible from the infeasible. Then cost can and should be included in the discussion. Once the development people take over the project, they will work to find ways to reduce the cost. But scientific research is fundamentally a search for knowledge and understanding; no stone should be left unturned.

A very long time ago, I made some special NdFeB magnets for a radiation study.[3] These magnets contained terbium. At the time, we knew that adding a few percent of terbium would increase the H_{ci} and that terbium was more effective than dysprosium, meaning that a small addition of Tb would increase the H_{ci} more than a comparable addition of Dy. However, terbium was rarely used in NdFeB magnets because terbium was significantly more expensive than dysprosium. Nonetheless I made these samples, when no one else would, so the scientists at Los Alamos could see if a different heavy rare earth element made a difference in the amount of flux lost when an NdFeB magnet is exposed to radiation. It turned out that both elements seemed equally effective at improving the radiation resistance; having high H_{ci} may be more important for radiation resistance than which heavy rare earth is used to achieve it. This was a good experiment because it produced new information. Since then, the relative prices of terbium and dysprosium have changed. Now we commonly see terbium used in NdFeB magnets. The technology didn't change, just the prices of these two heavy rare earths. Something that was extraordinary 20 years ago is commonplace today.

I realize that not everyone agrees with this idea and I am happy to give Drs. Gschneidner and McCallum, or anyone else who may have a different point of view, an opportunity to describe their approach. The primary reason I feel so strongly about this topic is that I have been involved in several projects where people tried to make things cheap long before they really had a handle on the material and process requirements for good results. In many of these projects, the outcomes were muddled and unsatisfactory, which I believe can be traced back to worrying about cost too early in the process. Again, we need to be smarter.

References

[1] Development of Improved Powder for Bonded Permanent Magnets, R. William McCallum, Magnetics Conference 2009

[2] Scandium, James B. Hedrick, U.S. Geological Survey, Mineral Commodity Summaries, January 2009, www.usgs.gov

[3] Radiation-Induced Changes in Magnetic Properties of Nd-Fe-B Permanent Magnets, R. D. Brown and J. R. Cost, IEEE Transactions on Magnetics 3117 (1989)

SRT

Spontaneous Materials

For Magnetics Magazine Winter 2009 issue