Earth, wind & fire

Maintenance work on a wind turbine motor which relies on the unrivalled strength of rare earth magnets to function.

Siemens

From wind turbines to missiles, rare earth based magnets can been seen as strategic in many ways. But why are they so special? Can they be replaced? And does the magnet industry have an over-reliance on a product derived from a source controlled by China and on the verge of a supply crisis? **Simon Moores** talked with Gareth Hatch of Technology Metals Research, LLC to find out

Magnets have been at the heart of the furore surrounding the rare earth industry. The present and future use of rare earth permanent magnets in key defence and green technologies, from missiles to electric vehicles to wind turbine generators' have been a primary reason for the attention that this group of elements now commands at government level.

This is not to mention the important role that they play in everyday items such as computer hard disk drives, loudspeakers and other household devices.

The most widely used magnet, neodymium-iron-boron (Nd-Fe-B), has not been changed since its invention in the 1970s such is its strength and performance at high temperatures, together with samarium-cobalt (Sm-Co).

While these elements have hit the headlines, it is actually the markets for these magnets which is why the world is racing for rare earths.

Why are rare earth-based permanent magnets so irreplaceable?

Gareth Hatch: Rare earth elements have magnetic, electronic and optical properties not found in any other element groups in the Periodic Table. This is primarily a result of the unique electronic structures found in these elements.

By combining certain rare earth elements with transition metals that exhibit magnetism, such as iron or cobalt, we can effectively "channel" the magnetic output of these elements, at the microscopic level, into a single "North-South" axis, leading to very strong magnets.

If we were to create same-sized samples of the types of magnet materials currently available, samples of Nd-Fe-B magnets would be able to put out the strongest magnetic field.

We use a figure of merit to compare magnet materials called the maximum energy product, or BHmax. Essentially this is the maximum amount of energy that can be stored by the magnet material, for a given volume, and is measured in thousands of joules per cubic meter (kJm^{-3}) or in millions of gauss oersteds (MGOe).

Commercially-available grades of Nd-Fe-B have the highest maximum energy products, around 52-54m. gauss oersteds (MGOe), compared to Sm-Co, which has up to 32 MGOe, Alnico, 5-7 MGOe] and ferrite, to a maximum of 4 MGOe].

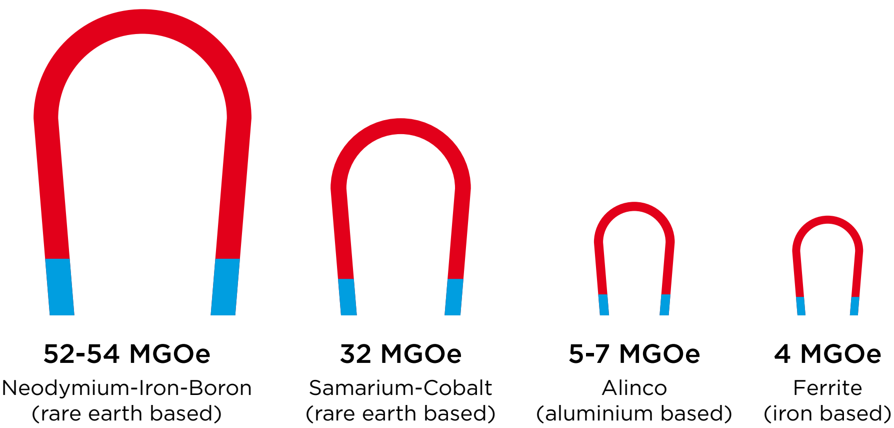
And for samarium magnets?

GH: Similar effects at the microstructural level are observed for Sm and its interaction with Co (and other elements), although the output is not quite as dramatic, or as powerful.

However, Sm-Co magnets are able to operate at much higher temperatures than Nd-Fe-B magnets before their useful magnetic output disappears, though in recent years the addition of dysprosium (Dy), a heavy rare earth element, to Nd-Fe-B magnets, has helped to increase the temperature resistance of those materials too.

It's really only rare earth elements like Nd and Sm (and some others) that can produce this "channelling" effect.

The strength of rare earths



Neodymium based magnets are nearly double the strength of samarium magnets and can be ten times stronger than those made predominately from aluminium and iron.

Are there any other special properties?

GH: As a result of the anisotropy, Sm and Nd-based magnets have very good resistance to being demagnetized by the presence of other magnetic fields. This allows us to build special assemblies with groups of magnet components that are arranged in certain ways so that the magnetic output is concentrated, leading to higher magnetic outputs than could be possible with a single magnet.

One thing to bear in mind with Nd-based magnets, in particular, is corrosion resistance. Because of the metallurgical structure of such materials, they are much more susceptible to corrosion than Sm-Co magnets, and thus Nd-Fe-B magnets are usually coated or plated before use.

Is volume of material a factor?

GH: Yes. Another way to look at the differences, tied into the energy product value mentioned earlier, is that if you want a certain magnetic output, then using Nd-Fe-B magnets means you need less volume of material to do it.

In other words, you can use smaller magnets made from Nd-Fe-B, compared to Sm-Co or other materials, to get the same job done. So anywhere where weight is at a premium, Nd-Fe-B would be the first choice magnet.

However, Sm-Co magnets are used in applications where a strong output is still required, but where the expected temperatures exceed those that Nd-Fe-B could handle. Examples might include the magnets used in missile sub-systems, or in the oil and gas drilling industry, where magnetics are used "downhole" as part of the surveying process. Note though that Nd-Fe-B magnets can still be used in a number of weapons systems.

Is there any way to make suitable magnets without rare earths?

GH: At the moment there is no way to produce permanent magnets with the same magnetic output as Nd-Fe-B and Sm-Co, without using rare earths.

There is some work that has been initiated recently to look for ways to produce such magnets, but it will be a tough challenge.

For example, some researchers in the USA and elsewhere, are looking into using combinations of Fe and Nd-Fe-B at the nanoscale, to produce strong magnetic materials. These would still contain rare earths, but less of them. This is a promising area but the challenges are very real, particularly in terms of production.

There is also work being done, mostly in Japan, to try to reduce the overall usage of heavy rare earth elements such as Dy in Nd-Fe-B magnets, while maintaining good, higher temperature characteristics. This is yielding some promising results already.

Note that the milestones in the development of permanent magnet materials are the result of significant materials science and engineering efforts. Understanding the underlying metallurgy, materials science and alloy chemistry is a critical key to the development of future materials.

Can we not just create a synthetic product that mimics the properties of rare earths?

GH: I would say that these magnet materials *are* in fact synthetic. The particular combinations of elements that form the magnetic compounds used in these magnets, are not found in nature and a lot of special processing has to be done to optimise the properties, even if you have the right recipe and all the right ingredients.

Magnets are a significant user of rare earths. However, there other major uses for rare earths, particularly for lanthanum and cerium. An example is the use of lanthanum in the production of fluid cracking catalysts for the petrochemical industry, used to convert the very viscous, high molecular weight hydrocarbons found in crude oil, into more useful, lower molecular weight hydrocarbons.

They are also key in catalytic convertors for automobiles – cerium oxide is combined with platinum group metals to make these devices work. Lanthanum and other rare earths can also be found in the alloys used for nickel-metal-hydride batteries, found in every Toyota Prius and other hybrid vehicles.

Does the magnet industry have an overreliance on a product based on a scarce resource?

GH: It depends on how you define "overreliance". At present, despite the media frenzy surrounding rare earths, there are no indications of problems of supply of finished rare earth permanent magnet materials, produced in China, to the West.

Recent discussions on export restrictions relate to the procurement of raw rare earths, and heavy rare earths in particular, not finished rare earth-based goods.

However, just because there have been no real problems to date, obviously this does not mean that the supply chain is not vulnerable. On the contrary, being reliant on a single geographic area such as China, regardless of the geopolitics involved, or even the materials in question, is clearly a strategic risk.

Security of supply is surely much more about the prevention of potential problems than it is about waiting for something bad to happen, and then dealing with the aftermath via some form of "plan B".

As such, many companies involved in the procurement of magnet materials for the production of end use magnet components and devices, are rightly concerned that the sources of supply are not diverse enough.

This is of course much easier to say, than to actually put into practice, but needs to be given some serious consideration.

Gareth Hatch is the founding principal of Technology Metals Research, LLC based in Chicago, USA. Until recently he was Director of Technology at Dexter Magnetics Technologies, a magnetic engineering and manufacturing firm. He still consults for Dexter on a regular basis.