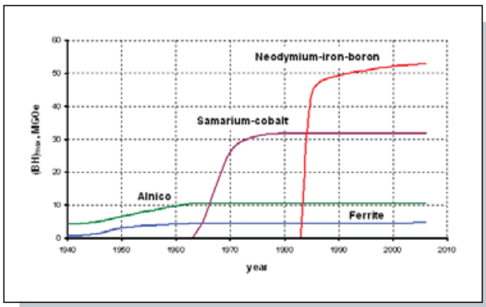
The Next Great Magnet

From my naming these columns "High Coercivity," you will realize how critical a property this must be for a permanent magnet. In fact, intrinsic coercivity is indeed an intrinsic property that indicates how "permanent" a magnetic material is. Following its manufacture, assembly and magnetization, a permanent magnet should ideally retain most of its net magnetization throughout all anticipated operating conditions. Intrinsic coercivity is the magnitude of demagnetizing field that would overcome the material's magnetization and reduce its net value to zero. So no matter how high the saturation magnetization of a material is, if it does not also possess a reasonably high intrinsic coercivity, you may have a pretty good soft magnetic material but a rather ineffective permanent magnet.

Notwithstanding the variety of permanent magnets that are now available using rare earth alloys, ferrite magnets still represent over 90 percent of the tonnage produced. And today's ceramic ferrite is not too different from the material that was invented over 50 years ago. Iron-based alloys have always been preferred for wide commercial application due to the abundance and low cost of this metal and for the opportunity to exploit as much as possible of iron's very high (almost 22 kG) saturation magnetization. The invention of neodymium-iron in 1981 sought to utilize both these benefits, but this simple alloy provided insufficient coercivity to make a useful permanent magnet. A year later, realization that the addition of boron substantially improved the coercivity led very quickly to the successful commercialization of neodymium-iron-boron (Neo). So 25 years have passed since the discovery of Neo, and many magnet users (not to mention investors) wonder when a new material will emerge to improve upon its properties.



Maximum energy product, (BH)max, is the quantity most commonly used to rate a permanent magnet material, for which both high saturation magnetization and high coercivity are required. In a very successful material such as Neo, its potential (BH)max is reached quite quickly in the development cycle, but historically such events have happened rather infrequently (see Figure). Ten years ago, a new type of rare earth-iron magnet was announced, which claimed to have a (BH)max about twice that of conventional Neo. This "Y.T. Magnet" was met with some skepticism and never demonstrated its claim of exceeding 120 MGOe. Not surprising really, when one considers that (BH)max of 120 MGOe requires the material to have a saturation magnetization of at least 22 kG (= 2 x v120) and an intrinsic coercivity exceeding 11 kOe. This would mean that pure iron would have to be given a high coercivity without noticeably diluting it in an alloy, as with a rare earth and/or any other element which conventional wisdom says is needed to develop coercivity.

Practical new materials using iron-based compositions have tended to show more promise using nitrogen rather than boron, nitrogen being a well-know alternative to boron for developing coercivity. Samarium-cobalt magnets from the early 1970's have used a Sm2Co17 alloy, and this same "2-17" type of composition has been adapted to samarium-iron-nitrogen as a Sm2Fe17Nx alloy. Magnetic properties of this alloy continue to improve to a (BH)max today of around 36 MGOe. The problem is that the inclusion of nitrogen would cause the compound to decompose at temperatures used for sintering, which precludes its application as a fully-dense magnet. However, samarium-iron-nitrogen has found success in bonded magnets for several years now, albeit with its energy product diluted about 50 percent.

Perhaps the last significant introduction of a realistic permanent magnet material was the commercialization four years ago of a Chinese invention (US Patent 6,419,759) using a neodymium-iron-nitrogen alloy. This is based on the "1-12" type of alloy composition (Nd1Fe12Nx), significantly different from Neo whose alloy is of the "2-14-1" type (Nd2Fe14B). But today the best powder of this alloy achieves a (BH)max of only around 24 MGOe, less than half that of the best Neo, and has a relatively poor intrinsic coercivity.

Research continues to be conducted in corporate and university laboratories throughout the world, the most prominent of which is reported at the International Workshop on Permanent Magnets, which is held every two years. But when the 19th meeting was held last year in Beijing, it was disappointing to note that the research effort is dwindling and that no papers were presented on developments that would lead to a new generation of commercial magnet material with properties superior to those of Neo. Much of the work is now focused on incremental improvements to the "2-14-1" type of alloy composition, even though neodymium-iron-boron most probably already represents the best that can be achieved here. In reality, the most favorable types of alloy composition to produce both high saturation magnetization and high intrinsic coercivity have been known and worked on for many years. So after 25 years, when will a new material emerge to improve upon the properties of Neo? Unfortunately the answer may be "no time soon" - but I really hope that I am wrong!

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