Cost Benefit of Additives for NdFeB

A few months ago in the December/January issue of this magazine, I suggested that we should probably get used to the idea that high prices will now prevail for neodymium and some other critical elements of neodymium-iron-boron (Neo) permanent magnets. In the same issue, Stan Trout asked for some explanation of the cost benefit of such critical elements, presumably on the resulting performance of a Neo magnet. This is a very important consideration in selecting the most cost effective magnet grade for any new application, and it is a topic that has generated the greatest interest and discussion at the strategic seminars I have been giving to select industry groups in recent years. So I would like to revisit a few of the critical elements whose supply and demand I discussed previously, now also looking at their cost benefit to the magnet's operating performance.

While new resources for rare earths are expected to come on-line from elsewhere within the next few years, China will remain the dominant global supplier of rare earth oxides and metals. But China has also been implementing a strategy to support the development of downstream rare earth industries, such as Neo magnets and to conserve its natural rare earth resources. It is doing this by tightening control over the rare earth oxides and metals that it exports, through the imposition of higher export duties and stricter export quotas. For 2008, the new tariffs on exported neodymium and dysprosium are 15 percent and 25 percent respectively, and the quota for all rare earth oxides and metals is 22,780 mT, about half the amount it exported the previous year; only 23 Chinese companies are now approved exporters, down from 41 in 2007. By taking these and other measures, the Chinese government has demonstrated its desire and ability to stabilize rare earth prices, albeit at relatively high levels.

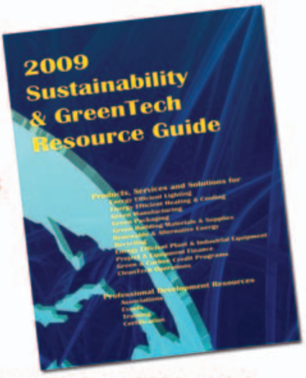
While almost all the neodymium metal exported from China now goes to customers in Japan, a strategy to hedge against China's export restrictions is already being implemented by Japanese producers of rare earth alloy and magnets, who are investing in new plants within China itself. All of the foregoing, coupled with the weakened US dollar against the Yuan, suggests that high prices have now become the status quo. So, after oscillating within a range of $40/kg to $50/kg over the past 12 months, the price of neodymium metal appears to have stabilized recently at around $42/kg. Compare this to the $28/kg I reported in this column for the end of 2006, or the $8/kg enjoyed only two years before that.

The ores that contain heavy rare earths such as dysprosium are much less abundant than those producing light rare earths and occur mainly in Southern China. As such, the price of dysprosium can also be affected quite quickly by controls in local regions, such as the recent temporary suspension of heavy rare earth production in areas of Jianxi province to counter weak demand. The price of dysprosium metal has risen steadily in recent years, leveling off recently at around $155/kg. To meet the demands of major new automotive applications such as motors for electric power steering and hybrid electric vehicle drives, dysprosium is substituted for some of the light rare earth neodymium in the composition to improve the magnet's intrinsic coercivity and hence provide resistance to demagnetizing fields at elevated temperatures, so there is a correlation between this and the magnet's raw materials cost. A wide variety of Neo magnet grades exists to allow selection of the one that gives the required intrinsic coercivity at the maximum temperature to be experienced in a particular application. For example, consider a motor that runs at 200°C and requires use of a sintered "EH" grade Neo magnet that has relatively high dysprosium content. Is it worthwhile switching to a "UH" grade, say, with less dysprosium and lower raw materials cost? The problem is that the significantly lower intrinsic coercivity of the UH-grade will require its resistance to demagnetization at this temperature to be compensated by additional magnet thickness (volume), and there is actually a net increase in raw materials cost of about 16 percent. Switching to the even lower coercivity "SH" grade raises this cost by about 32 percent. At least at today's prevailing prices for rare earth elements, the general rule appears to be that the required resistance to demagnetization for a Neo magnet should simply be achieved with the smallest possible thickness, regardless of the dysprosium content of the magnet grade which provides this.

Cobalt is an equally valuable component of a Neo magnet's composition, in which it is substituted for some of the iron to provide high temperature stability and improved corrosion resistance. Having cost as little as $15/kg several years ago, it peaked at $110/kg in January of this year because of short supply, and has subsequently fallen to around $95/kg. Unlike the rare earths, cobalt is just a bi-product of nickel and/or copper which is mined mainly in Africa, where many new production facilities are planned to come on-line over the next few years (mainly in the Democratic Republic of Congo). A world supply surplus of cobalt is projected for next year, followed by a continued downward price trend to around $25/kg by 2015. I have previously suggested that about 2 wt% of cobalt is sufficient for its beneficial effects to be realized, but probably no more than this because cobalt also degrades the intrinsic coercivity, partially offsetting the benefit of dysprosium. But, it also enhances the flux density of the material, which is particularly valuable for the lower energies inherent in bonded Neo magnets which are made using melt-spun powder. 2 wt% at \$25/kg amounts to a premium of only 50¢/kg for the material to have the benefits of cobalt, and if used in a typical compression-molded Neo magnet, more than 1 percent more magnetic flux will also be gained. With 4 wt% of cobalt at \$25/kg, the bonded Neo magnet gains about 2 percent flux for a premium of \$1.00/kg, still a particularly valuable cost benefit for the majority of these magnets used in consumer electronics which mostly weigh only a few grams or less.

So, the design of a device need not be compromised in order to save on the cost of Neo, either by the dysprosium needed for a sintered magnet or the cobalt needed for a bonded one.

Dr. Peter Campbell has been a consultant to permanent magnet producers and users for over 30 years. He has been a professor at the University of Cambridge and at the University of Southern California, and has worked with Magnequench Inc. as its head of Technology and head of Sales. Please contact him at drpeterc@earthlink.net, or visit www.magnetweb.com.



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Shenda M. Baker
Harvey Mudd College
tel. 909-621-8643
shenda_baker@hmc.edu

Michael R. Fitzsimmons
Los Alamos National Laboratory
tel. 505-665-4045
fitz@lanl.gov

Young-Chang Joo
Seoul National University
tel. 82-2-880-8986
ycjoo@snu.ac.kr

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or contact:

Member Services
Materials Research Society
506 Keystone Drive
Warrendale, PA 15086-7573
Tel 724-779-3003
Fax 724-779-8313
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C: Theory and Applications of Ferroelectric and Multiferroic Materials
D: Rare-Earth Doping of Advanced Materials for Photonic Applications
E: Materials and Technologies for 3-D Integration
F: Low-Cost Solution-Based Deposition of Inorganic Films for Electronic/Photonic Devices
G: Organic and Hybrid Materials for Large-Area Functional Systems
H: Physics and Technology of Organic Semiconductor Devices
I: Reliability and Properties of Electronic Devices on Flexible Substrates
J: Material Science for Quantum Information Processing Technologies
K: Magnetic Nanostructures by Design
L: New Materials with High Spin Polarization and Their Applications

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O: Structure/Property Relationships in Fluorite-Derivative Compounds
P: Photovoltaic Materials and Manufacturing Issues
Q: Scientific Basis for Nuclear Waste Management XXXII
R: Materials for Future Fusion and Fission Technologies
S: Solid-State Ionics
T: Mobile Energy
U: Advanced Intermetallic-Based Alloys for Extreme Environment and Energy Applications

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V: Materials, Devices, and Characterization for Smart Systems
W: Computational Materials Design via Multiscale Modeling
Y: Biomineral Interfaces—From Experiment to Theory
Z: Mechanics of Biological and Biomedical Materials
AA: Materials for Optical Sensors in Biomedical Applications
BB: Polymer-Based Smart Materials—Process, Properties, and Application
CC: Design, Fabrication, and Self Assembly of "Patchy" and Anisometric Particles
DD: Materials in Tissue Engineering

NANOSCIENCE
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FF: Nanofunctional Materials, Structures, and Devices for Biomedical Applications
GG: Microelectromechanical Systems—Materials and Devices II
HH: Advances in Material Design for Regenerative Medicine, Drug Delivery, and Targeting/Imaging
II: Bio-inspired Transduction, Fundamentals, and Applications
JJ: Nanotubes, Nanowires, Nanobelts, and Nanocoils—Promise, Expectations, and Status
KK: Transport Properties in Polymer Nanocomposites
LL: Nanowires—Synthesis, Properties, Assembly, and Application
MM: Applications of Group IV Semiconductor Nanostructures
NN: *In-situ* Studies across Spatial and Temporal Scales for Nanoscience and Technology
OO: Grazing-Incidence Small-Angle X-Ray Scattering
PP: Solid-State Chemistry of Inorganic Materials VII
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RR: Artificially Induced Grain Alignment in Thin Films
SS: Selecting and Qualifying New Materials for Use in Regulated Industries
TT: Local Structure and Dynamics in Amorphous Systems

GENERAL INTEREST
X: Frontiers of Materials Research

Meeting Activities

Symposium Tutorial Program

Available only to meeting attendees, the symposium tutorials will concentrate on new, rapidly breaking areas of research.

Exhibit

A major exhibit encompassing the full spectrum of equipment, instrumentation, products, software, publications, and services is scheduled for December 2-4 in the Hynes Convention Center. Convenient to the technical session rooms and scheduled to complement the program, the MRS Fall Exhibit offers everything you need all under one roof.

Publications Desk

A full display of over 950 books will be available at the MRS Publications Desk. Symposium Proceedings from the 2007 MRS Fall Meeting and 2008 MRS Spring Meeting will be featured.

Student Opportunities

Graduate students planning to attend the 2008 MRS Fall Meeting are encouraged to apply for a Symposium Assistant position and/or a Graduate Student Award. Applications will be accessible on the MRS Web site by June 1.

Career Center

A Career Center for MRS members and meeting attendees will be open Tuesday through Thursday.