The Weekly Newsmagazine of Science

SCIENCE NEWS

August 8, 1987
Vol. 132, No. 6
Pages 81-96

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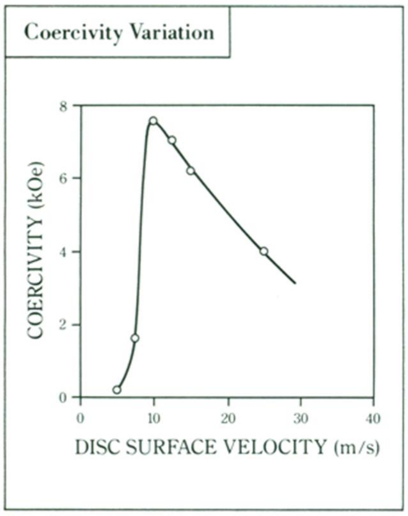
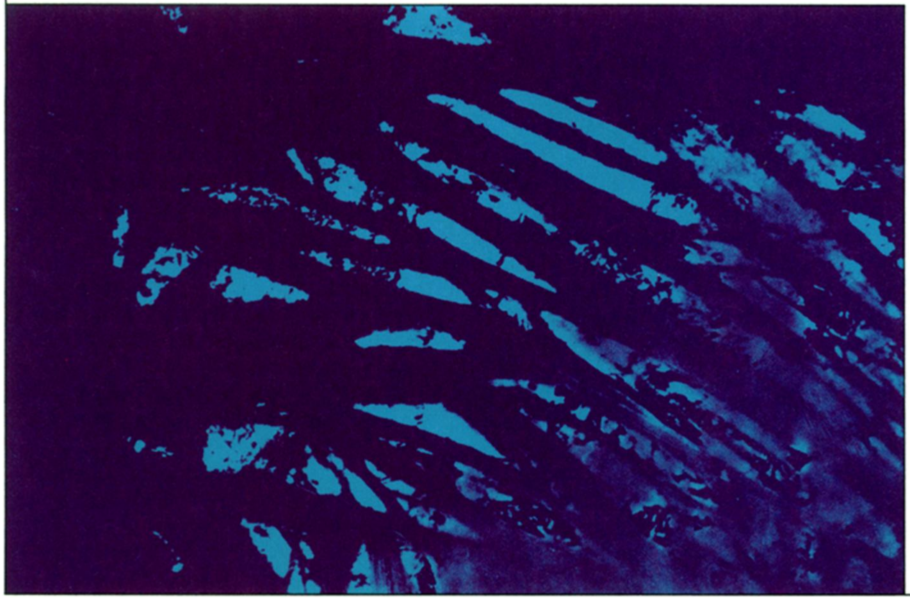
The Critical Interval

There has long been a need in the industrial world for low-cost, high-performance permanent magnets. Discoveries at the General Motors Research Laboratories have led the way toward meeting this challenge by the application of new preparation techniques to new rare-earth magnetic materials.



Coercivity of $Pr_{0.4}Fe_{0.6}$ plotted as a function of disc surface velocity.

Color-enhanced transmission electron micrograph of melt-spun $Nd_{0.4}Fe_{0.6}$ having 7.5 kOe coercivity.



TWO properties characterize desirable permanent magnets: large coercivity (magnetic hardness or resistance to demagnetization) and high remanence (magnetic strength). Higher-performance magnets are required to reduce further the size and weight of a wide variety of electrical devices, including d.c. motors. Such magnets are available, but the cost of the materials necessary to produce them severely limits their use. The research challenge is to select, synthesize, and magnetically harden economically attractive materials of comparable quality.

Prominent among alternative materials candidates are alloys composed of iron and the abundant light rare earths (lanthanum, cerium, praseodymium, neodymium). Investigations conducted by Drs. John Croat and Jan Herbst at the General Motors Research Laboratories have led to the discovery of a method for magnetically hardening these alloys. By means of a rapid-quench technique, the researchers have achieved coercivities in Pr-Fe and Nd-Fe that are the largest ever reported for any rare earth-iron material.

Drs. Croat and Herbst selected praseodymium-iron and neodymium-iron based upon fundamental considerations which indicate that these alloys would exhibit properties conducive to permanent magnet development. These properties include ferro-magnetic alignment of the rare earth and iron magnetic moments, which would foster high remanence, and significant magnetic anisotropy, a crucial prerequisite for large coercivity.

That these materials do not form suitable crystalline compounds, an essential requirement for magnetic hardening by traditional methods, presents a major obstacle. Drs. Croat and Herbst hypothesized that a metastable phase having the necessary properties could be formed by cooling a molten alloy at a sufficiently rapid rate. They tested this idea by means of the melt-spinning technique, in which a molten alloy is directed onto a cold, rotating disc. The cooling rate, which can be varied by changing the surface velocity of the disc, can easily approach 100,000°C per second. The alloy emerges in the form of a ribbon.

THE researchers found that variations of the cooling rate can dramatically affect the magnetic properties of the solidified alloys. In particular, appreciable coercivity is achieved within a narrow interval of quench rate.

Equally remarkable, synthesis and magnetic hardening, two steps in conventional processing, can be achieved simultaneously.

"X-ray analysis and electron microscopy of the high coercivity alloys reveal an unexpected mixed microstructure," states Dr. Croat. "We observe elongated amorphous regions interspersed with a crystalline rare earth-iron compound."

Understanding the relationship between the coercivity and the microstructure is essential. The two scientists are now studying the extent to which the coercivity is controlled by the shape and composition of the amorphous and crystalline structures.

"The development of significant coercivity is an important and encouraging step," says Dr. Herbst, "but practical application of these materials requires improvement of the remanence. Greater knowledge of the physics governing both properties is the key to meeting the commercial need for permanent magnets."

TECHNOLOGY UPDATE: 1987

Subsequent to the research reported above, Drs. Croat and Herbst added boron to neodymium-iron as a glassifier to increase the formation of the elongated amorphous regions they had observed in the material. They reasoned that shape anisotropy, and thus coercivity, was related to the presence of these amorphous micro-needles.

They discovered that the addition of boron promoted the formation of a previously unknown ternary compound: $Nd_2Fe_{14}B$. Its atomic magnetic moments are arranged so that this compound has a large magnetization. At the same time, the researchers found that, compared with neodymium-iron, coercivity had risen from 8 to 20 kOe, and that the magnetic energy product had increased by a factor of seven.

On March 31, 1987, General Motors dedicated a new Delco Remy plant in Anderson, Indiana for the production of magnetic material and finished magnets made from $Nd_2Fe_{14}B$ under the commercial name MAGNEQUENCH.

THE MEN BEHIND THE WORK

Dr. John Croat and Dr. Jan Herbst did their original work on rare-earth magnetic materials when both were Staff Research Scientists in the Physics Department at the General Motors Research Laboratories.

Dr. Croat (right) holds a Ph.D. in metallurgy from Iowa State University. In 1984, he joined GM's Delco Remy Division to stabilize the melt-spinning process for the commercial production of MAGNEQUENCH materials. He is currently Chief Engineer at the Indiana plant.

Dr. Herbst received his Ph.D. in Physics from Cornell University. He is now a Senior Staff Research Scientist and Manager of the Magnetic Materials Section in the Physics Department of the GM Research Laboratories. His research interests also include photo-emission theory, the physics of fluctuating valence compounds, and superconductivity.

Dr. Croat joined General Motors in 1972; Dr. Herbst in 1977.