

Classic Magnet Materials



As you may have noticed, most permanent-magnet talk around the water cooler of late has been about NdFeB. Admittedly, this is an exciting material with unique and extraordinary properties; however, it is not the best material for all applications. Most permanent magnets used today are not NdFeB. There are many pre-NdFeB

magnet materials still in use. CrCoFe, CuNiFe, and PtCo are still in action. But Alnico, ferrite and SmCo materials are the most extensively-used classics.

Alnico Magnets

In the 1930s, the first aluminum nickel iron magnet alloy was cast. Not quite an Alnico, but a real predecessor. Anisotropic Alnico was introduced in 1940 and significant quantities were delivered in that decade. In 1957, 25 percent of the cobalt used in the US went into alnico magnets.

Alnico is composed of aluminum, nickel, cobalt, a little copper and a lot of iron. The grades with the highest induction are the Alnico 5's. The materials with the higher coercivities are the Alnico 8's; most of today's Alnicos are eight grades. Alnicos boast the lowest temperature coefficient of all permanent magnet grades over a large temperature range. They have high inductions and are easy to magnetize. These materials are very resistant to corrosion; salt, heat and moisture are no problem for standard grades.

Most Alnico magnets are cast and the finish grinding processes can be relatively extensive. Smaller Alnico magnets can be made less expensively when, instead of casting, the alloy is crushed into powder then cold pressed and sintered (most sintered Alnico parts weigh less than an ounce). One third of the Alnico magnets used in this country are sintered and are about 97 percent dense.

Anisotropic Alnico materials go through a subsequent heat-treat cycle which sets the direction of anisotropy and enhances the energy product. Because the direction of anisotropy is set after the physical structural is formed; straight-through, diametrical, cylindrical, and other curved field orientations are possible. Lower induction isotropic magnets are also available and can be magnetized in any direction.

Today's Alnico applications are typically in those areas where the device must perform similarly regardless of large temperature excursions or just where very high temperatures are seen. Because the magnetic poles are recessed back into the magnet, they are also used in motor applications where a soft start is required or where motor cogging could be problematic. Sometimes steel pole pieces will be affixed to the magnets, in higher-demag applications, so that the large demagnetizing forces will be partially directed away from the magnet as leakage flux.

Alnico applications include down-hole oil exploration/drilling, seismometers and hysteresis couplings.


Alnico Magnets

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| <ul style="list-style-type: none"> • Mfg. Processes:
Casting or Sintering • Basic Raw Materials:
Al, Ni, Co, & Fe • Major Grades:
Cast: 2, 5, 5-7, 8, & 9
Sintered: 2, 5, & 8 • Advantages:
High induction
Very low temp. coefficient
High resistance to corrosion
Easy to magnetize | <ul style="list-style-type: none"> • Disadvantages:
Low resistance to demag
High Cobalt content • Major Applications:
Sensors
Motors
Military
Meters Where very high temperature extremes exist and/or where very stable properties are required in environments where demagnetizing fields are not great |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

Aircraft, spacecraft and military applications motors and sensors often require Alnico magnets. Application areas where the magnetic field must remain unchanged for decades usually employ Alnico magnets. The large variety of alignment directions enables the design of motors, meters and other devices that would not work with a typical straight-through alignment. Alnico guitar pickups are said to have superlative tonal quality.

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Ferrite Magnets (aka Ceramic Magnets)

In the late 1930s, ferrite magnets were reported to have been created from iron oxide. This shouldn't have been such a stretch since lodestones (of similar chemistry - Fe_3O_4) were noted by Greek scientists/philosophers in 600 BC. The simple recipe of today's ceramic magnets is $SrO \cdot 6Fe_2O_3$ and has changed very little since the 1940s (barium was/is sometimes used instead of Strontium). Spices are sometimes added to the mix; but, over the years, most property improvements have been made through improvements in the manufacturing processes and access to superior raw materials.

About 50 percent of the global magnet market is ferrite. The ceramic magnet manufacturing process is one geared for high production volumes, thus production tooling is significantly more costly than that of other magnet materials. However, the individual ferrite magnet's price will be much less than that of any other magnet material of the similar size because all of the raw materials are inexpensive and because of the economy of scale. Ferrite magnets are used where price is more important than size or weight and where temperature extremes and temperature-related changes in induction are not problematic. Ferrites are immune to most corrosive environments since they are pretty-much made from rust and dirt.

As in Alnico materials, the ceramic 5 grade has the higher induction and the 8 grade has the greater coercivity. High induction ferrite magnets are typically used for small high-performance motors and speakers. Automotive applications such as fuel pump, window lift, small compressors and sensors are common. Clock motors and stepper motors will also thrive on this high-induction ferrite material. The more basic ceramic magnet materials have lower coercivity and are utilized in huge volumes of speakers, material separation devices, switches, and holding applications (i.e. cabinet latches, trunk-mount devices, and "strong" refrigerator magnets).

High coercivity grades are used where the temperature may be low, or where larger demagnetizing forces are witnessed; often in larger torque motors. Automotive applications include the starter, power steering pump, power brake pump and wiper motors. Washing machine motors, garage door lift motors, larger compressor motors, elevator lift motors, electric winches and a very large number of industrial motors will use these materials and improve their performance with the larger drive currents.

There are also a large number of applications that require both high induction and high coercivity; the high-energy grades. For instance, the ceramic 4X4 (4 kG Br and 4 kOe Hci) is often used to miniaturize high performance motors. Automotive motor applications include the engine cooling fan, power steering pump (for smaller vehicles) and the door lock actuators. Compressors, power tools, CD-DVD motors, cameras, fan motors (used everywhere), the kitchen mixer, can opener, coffee machine, small engine magnetos, the bathroom shaver and the toothbrush motors

enjoy flux from these grades.

Radially-oriented ferrite rings are available in limited sizes. These are often used in small brushless motors (such as stepper motors) or in rotational position sensors. Because the alignment is through the magnet wall, a steel flux return path is typically required. That flux return path becomes unnecessary if we orient the ring with discrete poles. When the pole count and the magnet wall thickness are chosen properly, the direction of anisotropy can curve inside the magnet. The magnet will still be anisotropic, thereby having a higher energy product, and the permeance coefficient of the magnet is increased. The flux density pattern of the multipole rings is often desired by motor engineers because the magnitude of the flux varies with the rotational angle in a sinusoidal pattern. These discrete pole rings are noticeably more costly than other ferrite magnets and are currently available only in limited sizes.

Ferrite Magnets	
<ul style="list-style-type: none"> • Mfg. Processes: Sintering 	<ul style="list-style-type: none"> • Disadvantages: Low induction Very high temperature coefficients
<ul style="list-style-type: none"> • Basic Raw Materials: $MO \cdot 6Fe_2O_3$ (where M is Sr or Ba) 	<ul style="list-style-type: none"> • Major Applications: Motors / actuators Speakers Magnetos / generators Torque couplings Separators Lifting / holding
<ul style="list-style-type: none"> • Major Grades: 1, 5, 8, 9, & 12 	
<ul style="list-style-type: none"> • Advantages: Very low cost Great abundance of raw materials High resistance to corrosion 	<ul style="list-style-type: none"> Where cost is a greater concern than size and weight

SmCo Magnets

In the 1960s, while a civilian researcher at the Wright-Patterson Air Force Base Materials Laboratory in Dayton, Ohio, Dr. Karl Strnat was attempting to better understand the origins of magnetic properties. He tried many possible compounds; and in 1966 he discovered that $SmCo_5$ (Samarium-Cobalt) had an energy product much greater than that of any previous permanent magnet. The discovery of this class of magnets, known as rare earth permanent magnets, enabled significantly more powerful devices to be manufactured in significantly smaller package sizes and opened new routes of research for even more powerful magnet materials.

Samarium is not the cheapest rare earth element, so efforts to replace it continued. Cobalt is one of the more expensive transition metals, so efforts were also made to replace it. This research led to the development of the Sm_2Co_{17} magnet materials that have higher energy products and lower temperature coefficients. Sm_2Co_{17} has more ingredients than its name suggests. One (of many) more detailed chemistries is; $Sm_2(Co, Cu, Fe, (Ti \text{ or } Zr), C)_{17}$. NdFeB magnets are also a direct result of further research on the rare earth - transition metal recipe.

The thought process in selecting SmCo over other materials is often similar to that used in selecting Alnico. The low

temperature coefficients of induction and coercivity reflect the material's stability over a large temperature range. By switching some lanthanide series metals, even zero temperature coefficient (over a limited temperature range) magnets can be produced. Also like Alnico, the

Samarium Cobalt Magnets	
<ul style="list-style-type: none"> • Mfg. Processes: Sintering 	<ul style="list-style-type: none"> • Disadvantages: High cost Nonabundant raw materials
<ul style="list-style-type: none"> • Basic Raw Materials: Sm, Co, Cu, Fe, Ti, Zr, C 	<ul style="list-style-type: none"> • Major Applications: Motors Sensors Ion vapor deposition Military TWT
<ul style="list-style-type: none"> • Major Grades: SmCo₅ or Sm₂Co₁₇ 	
<ul style="list-style-type: none"> • Advantages: Low temperature coefficient Good resistance to corrosion High Induction / Energy / Hci Highest output @ temps > 150°C 	<p>Where high stability over a wide range of temperatures and/or large resistance to demagnetization @ high temperatures are required</p>

SmCo materials stand up well against oxidation and corrosion. Unlike Alnico, these have; high energy products, high Hci's, and require high magnetizing fields.

SmCo magnet-containing devices are extensively used in rocket, airplane and spacecraft applications due to the harsh environments experienced and to the ability to minimize material weight. They are used in many high-temperature terrestrial devices such as sensors, vapor depositions systems and high temperature motors. Even if an NdFeB magnet can enable your application at its maximum temperature; you may still want a SmCo material in order to reduce your temperature-range induced performance change by two thirds. When you require a low temperature coefficient magnet with high energy in a small package, you will probably choose SmCo material.

Conclusion

Most magnets used today are still from the Alnico, ferrite and Samarium Cobalt group of classics. Each of these materials has unique attributes that make it irreplaceable and guarantee its continued use. Research continues on these materials; both in their composition and in their manufacturing processes. New designs, of old and new permanent magnet-containing products, continue to demand unique properties only found in this classic group of materials.

Mike Guthrie has been an engineer in the magnetics field for more than 25 years. He has worked for Hitachi Magnetics, the Magnequench business unit of General Motors, Stackpole Magnetics, Crumax Magnetics and Vacuumschmelze. Currently, he is the director of Engineering for the Quadrant Magnetics Group. He can be contacted at m.guthrie@quadranttechnology.com.

2008 Innova Awards

The Innova Awards are announced annually by MB&T magazine and feature leading companies within the magnetics market who have shown through their products and services, the most innovative and advanced technology breakthroughs. These awards are designed to recognize companies that are striving for excellence in industry leadership, product development excellence, best technology and outstanding magnetics applications.

Nominations will be accepted only electronically by email. Submit to Heather Krier: heatherk@infowebcom.com.

All nominations must be received by August 1, 2008.



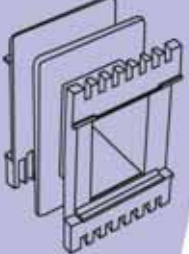
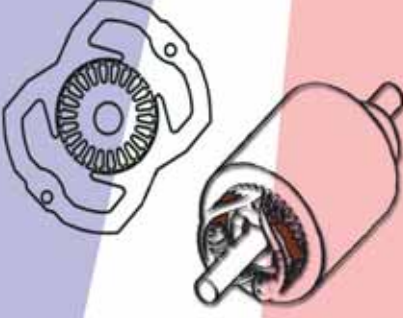
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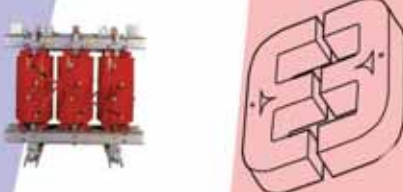

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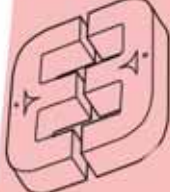
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