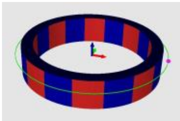

D. Magnetic Materials

Table D.1 shows an overview of the most common materials which are in use for industrial and commercial applications. Fig. D.1 provides sketches for typical demagnetization curves. The table shows representatives values only, as each material class can cover a wide range of qualities.

Material	Strength	Magnetic Stability	Thermal Behavior	Chemical Stability	Costs	Applications
Ferrite (1952)	low Br=0.45T	midrange $_IH_c$=280kA/m	variations with T T_{kBr}=-0.2%/K	excellent	very low	high quality sensors, low power motors, low level applications
Alnico (1932)	midrange to High Br=1.0T	low $_IH_c$=80 kA/m	excellent T_{KBr}= -0.02%/K	good	moderate to high	sensors, measuring devices
NdFeB (1983)	very high Br=1.4T	excellent $_IH_c$=1600 kA/m	variations with T T_{KBr}= -0.13%/K	magnetic losses by oxidation and corrosion	high	permanent magnetic motors, long range sensors
SmCo (1968)	high Br=1.2T	excellent $_IH_c$=800 kA/m	excellent T_{KBr}= -0.035%/K	adequate	very high	permanent magnetic motors, sensors, measuring devices

Table D1.: Most common hard magnetic materials with typical inherent parameters.

The first developed hard magnetic material for mass production, i.e. alnico, slowly runs out of fashion. This mainly originates from its low stability against external fields and temperature, which follows from its bent demagnetization curve. This makes Alnico magnets unstable against irreversible changes nearly over the whole range of possible working points. For real applications the magnets have to be stabilized by a partial demagnetization process, so that the working points are located on inner branches of hysteresis, compare to Part C. On the other hand, Alnico shows the lowest temperature variations under reversible changes, caused by the small temperature coefficient of this parameter. This is the main reason, that Alnico is still in use, especially in measuring devices like watthour meters or other.

Ferrites are still the most popular hard magnetic materials. Their low prices together with their high magnetic stability make them most attractive especially for mass applications in automotive or electronic industry. The J(H)-curve has a good rectangularity, which results in a good stability against varying external fields or temperature variations. On the other hand coercivity and saturation field strength are not that large, so that relatively small fields are sufficient to magnetize magnets into saturation. This makes it possible to apply even very small and also complicated pole structures, which makes Ferrites especially preferable as field sources for sensor applications. Additionally Ferrites are chemically very stable, so that as good as any long term changes or losses of magnetic induction can be excluded. All these reason make Ferrite materials so attractive. At the development of magnetic products one tries to compensate the relatively low remanence induction of Ferrites to benefit from all the other advantages

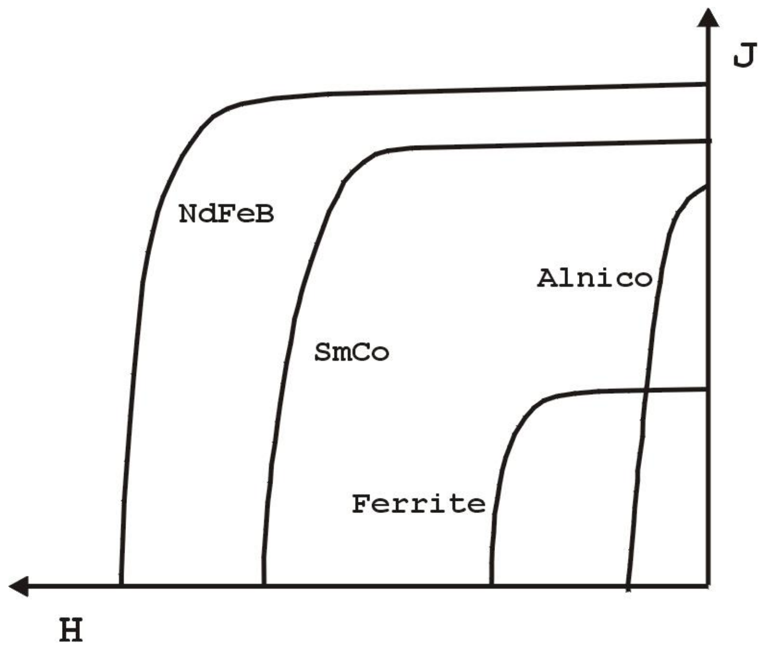

Fig.2: J(H)-curves for the most common permanent magnetic materials

If very high fields or forces are needed Rare Earth materials like NdFeB or SmCo are applied. NdFeB provides the highest remanences, i.e. values over 1.5 T are possible with sintered, anisotropic magnets. Especially in sintered magnets the demagnetization curve is more or less rectangular. Together with a large coercivity this is the reason for an excellent stability, especially against magnetic losses by external fields. This makes theses material preferable for permanent magnetic machines or for generators. On the other hand the large coercivity is an obstacle for realizing complicated magnetic structures. Another disadvantage, especially of NdFeB, can be found in its tendency to lose parts of its magnetic strengths with time, especially at large temperatures. This is caused mainly by oxidation or corrosion and leads very often to the necessity to cover its surface with coatings made of metals or resins.

SmCo is a material with excellent characteristics in nearly all technical fields. Its only disadvantage can be found in its very high price, which mainly originates from the high Co content. A large remanence induction is combined with a good rectangularity and a high coercivity, which makes the magnets very stable against thermal or field originated losses. Also the chemical stability is good. The reversible field variations with temperature are very small, so that SmCo is attractive both for motor as well as for sensor applications.

The market for permanent magnets is currently also penetrated by relatively new materials like SmFeN. Generally it can be stated that SmFeN is a material comparable to NdFeB with respect to remanence. Coercivity is similar to that of some SmCo alloys. Problems with thermal stability at high temperatures had been reported over longer periods of the world wide attempt to develop an industrially applicable material. Momentarily SmFeN is only available in the powder state, which is used for the production of bonded magnets.

Whereas in the past the above listed materials were used mainly in the form of cast or sintered magnets, which were described by the above values in table D.1, today so called bonded magnets more and more enter the market. In the past such magnets were mainly known for technical low level applications, but during the last 20 years increased amounts of those magnets have been used by automotive and electronic industries. Bonded magnets are made by a blending magnetic powder with polymers. This means that e.g. 60% of the magnets volume consists of magnetic material in powder shape and the rest of polyamide, epoxy resin or other. One great advantage of these composites is the usability of production methods of plastics industry, which leads to an easy mass production of magnets with most complicated geometries at lowest costs. Other interesting characteristics are based on the high variety of inherent magnetic structures, which lead to large degrees of freedom in the design of resulting magnetic fields. Disadvantageous in comparison to sintered specimen is the low remanence induction.