Magnetic Materials: History

The history of permanent magnetism dates back over many centuries. The earliest observations of magnetism can be traced back to the Greek philosopher Thales in the 6th Century B.C. However, it was not until 1600 that the modern understanding of magnetism began.

1600: Dr. William Gilbert published the first systematic experiments on magnetism in "De Magnete"
1819: Oerstead accidentally made the connection between magnetism and electricity discovering that a current carrying wire deflected a compass needle.
1825: Sturgeon invented the electromagnet.
1880: Warburg produced the first hysteresis loop for iron.
1895: The Curie law was proposed.
1905: Langevin first explained the theory of diamagnetism and paramagnetism.
1906: Weiss proposed ferromagnetic theory.
1920s: The physics of magnetism was developed with theories involving electron spins and exchange interactions; the beginnings of quantum mechanics.

The progress of permanent magnetic materials proceeds in a series of steps. Each material is developed and improved before being supplanted by a new one. This trend is shown in figure 1a which shows the development of permanent magnet materials throughout the 20th century. The graph shows the improvement in maximum energy product of the materials, which is used as a figure of merit, as it is a measure of the ability of magnets to do work per unit volume of material. The reduction in size of magnets is illustrated more vividly in figure 1b.

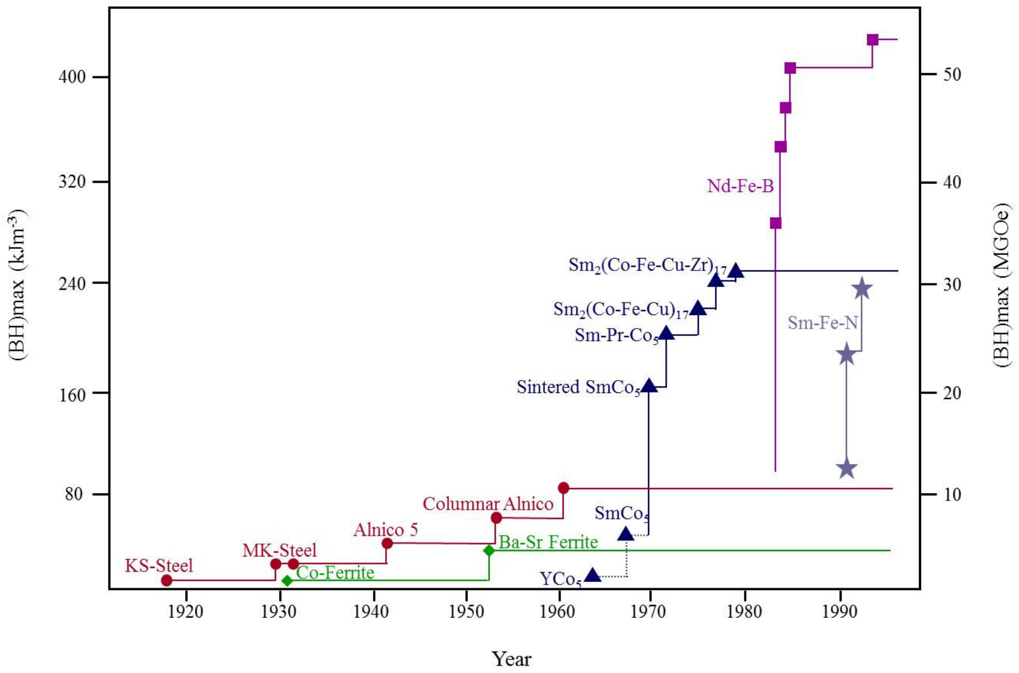

Figure 1a: *The development of permanent magnets in the 20th Century. BHmax has improved exponentially, doubling every 12 years.*

Figure 1b: *Brass bound lodestone, ferrite block and NdFeB magnet: each store the same magnetic energy (~0.4J) & contain ~70% iron by weight, yet the mass has decreased a thousand fold.*

Lodestone:
This was the first permanent magnet to be recognised; a naturally occurring oxide Fe3O4. Lightning strikes are thought to be responsible for the large magnetic fields that initially magnetised the rocks. The magnetic field produced is low, however, the resistance to demagnetisation is reasonably high.

Magnetic Carbon Steel:
These were developed in the eighteenth century. These steels are normally alloyed with tungsten and/or chromium to form carbide precipitates under appropriate heat treatments, which are effective in obstructing domain wall movement. These magnets have a high magnetic saturation, far superior to lodestone, however, they are prone to demagnetisation necessitating the use of long shapes to minimise demagnetisation fields.

Alnico Magnets: (alloys based on Al, Co, and Ni):
This group of magnets, developed in the 1930s, were the first modern permanent magnets offering considerable in magnetic hardness over the magnetic steels previously available. Their properties rely on the shape anisotropy associated with the two phase nanostructure comprising of ferromagnetic Fe-Co needles in a matrix of non-magnetic Al-Ni. Due to their high Curie temperature, ~850℃, they are still used for certain applications today.

Cobalt Platinum Magnets:
These were developed in the 1950s. Their improved properties over the Alnico's and corrosion resistance made them an ideal candidate for use in biomedical applications at the time. However, due to their high cost they did not gain widespread use and the rare-earth magnets superseded them.

Hard Ferrite Magnets: ($BaFe_{12}O_{19}$ or $SrFe_{12}O_{19}$):
These have been of most important commercial magnets for the last few decades. Due to their anisotropic structure they exhibit relatively high coercivity, however, the energy product is low.

Despite this they have found widespread use, as the abundance of the raw materials is high and production costs are low they are also suitable for use in complex shapes. As a result they still remain the most common magnetic material in bulk applications.

Samarium Cobalt:

Developed in the late 1960s this group of alloys combine cobalt, iron and a light rare earth element; many exhibit high energy hard magnetic behaviour, but SmCo5 is as yet the only one of commercial significance. These held the record for highest energy product for many years; unfortunately they have the disadvantage of being costly. These magnets have good thermal stability and are therefore used in applications where the magnets will be exposed to high temperatures.

Neodymium Iron Boron Magnets:

These were first produced in 1984; they combine a high saturation magnetisation with good resistance to demagnetisation. The high cost of samarium and the instability in the price of cobalt led to these magnets becoming the material of choice for applications requiring high energy magnets. Despite the high energy product these magnets have a relatively low Curie temperature (312℃) which limits their use in high temperature applications: additions of Co and Dy improve the temperature characteristics but also increase the production costs. This has not, however, prevented them being used increasingly in the marketplace, especially in applications where miniaturisation is an important design criteria.

Samarium Iron Nitride:

The development of these alloys is still ongoing; they are a promising new candidate for permanent magnet applications due to their high resistance to demagnetisation, high magnetisation and increased resistance to corrosion and temperature when compared with neodymium iron boron.