PERMANENT MAGNET MATERIALS

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INTRODUCTION

The intention of this paper is to describe the processing, properties and uses of the two major groups of permanent magnetic materials produced by powder processing. These are the hard ferrite and rare earth permanent magnet groups.

Permanent magnets are used in a wide range of industrial, domestic, automotive and aerospace applications. The current uses of permanent magnets in domestic applications averages 50 per household in Western Europe. The total permanent magnet sales in 1987 are valued at £950 x 10^6 and this market is expected to expand at 10% per annum for the coming years.

The special technological importance of permanent magnets derives from their ability to act contactlessly on ferromagnetic material, either by attraction or replusion, and to provide a permanent magnetic flux with no energy input and hence at no operating cost.

The continuing improvement in magnetic materials together with advances in power and integrated electronics has seen the development of a wide range of devices in which field coil windings are replaced by permanent magnets. Examples include brushed permanent magnet motors for automobile accessory applications and brushless permanent magnet motors for a wide spectrum of applications, ranging from computer disk drives to actuators for aircraft flight control surfaces.

The continuously reducing market price levels of permanent magent components, brought about by cheaper raw materials and improved processing efficiency, is generating an expanding variety of devices were electromagnetic field system are being substituted by a cheaper permanent magnet circuit.

The market today is dominated by two classes of material; one ceramic (Sr / Ba hexaferrite permanent magnets) and one metallic (rare earth permanent magnets).

Philips have recently announced the manufacturing and marketing of a new range of rare earth permanent magnets based on the $NdFe_{14}B$ system. These Neodure magnets are currently available covering a range of grades which complement the established rare earth grade (RES 190) based on the $SmCo_5$ system.

The improvement in primary magnetic properties of the NdFe - based magnets over the existing high energy SmCo - based magnets and ferrite magnets is illustrated in the table below.

COMPOSITION	$Nd_2Fe_{14}B$	$SmCo_5$	$SrFe_{12}O_{19}$	
	RES270	RES190	FXD380	
Br typical	1.1	0.89	0.39	T
BH max typical	215	154	28.2	KJ/m3
Temperature coefficient of Br (20 to + 150°C)	-0.13	-0.04	-0.2	%/K
Temperature coefficient of HcJ (20 to 150°C)	-0.6	-0.05	0.34	%/K
Recoil permeability	1.05	1.05	1.1	
Curie point	310	720	450	°C
Max continuous operating temperature.	120	250	350	°C
Density	7.4	8.3	4.75	x10 3 kg/m3

Sr / Ba HEXAFERRITE PERMANENT MAGNETS

The majority of permanent magnets produced are of the ceramic hard ferrite material type with the composition $MeFe_{12}O_{19}$ (where Me is Sr or Ba). These materials account for 66% of the sales value of the total permanent magnet market and have been in commercial production since the early 1950's. Their magnetic properties are characterised by relatively low values of maximum energy product, (BH) max, and remanence, Br. Their resistance to demagnetisation or polarization coercivity, HcJ, is much higher than earlier steel - based and AlNiCo materials. The parameters HcJ and (BH) max are considered to be the two most important indicators of permanent magnet performance.

The two major applications of hard ferrite are loudspeaker rings and stator field segments for automobile D.C. motors. Some components are produced with isotropic magnetic properties and some with anisotropic properties. Anisotropic magnets have improved (BH) max values over isotropic materials.

An outline of the process technology to produce a wet pressed anisotropic component is shown below:

Blend and mill raw materials (Sr or $BaCo_3$ and Fe_2O_3 + minor additions).

↓

Granulate

↓

Prefire in the range 1273K to 1373K to form the hexaferrite compound.

↓

Wet ball mill (multi-stage) to <1.2 m.

↓

Decant slurry to required solids content.

↓

Wet press segment shape in radial magnetic field in multi-cavity tooling.

↓

Dry

↓

Sinter in range 1473K to 1573K.

↓

Grind using diamond wheels.

↓

Test, pack and magnetise if required.

Increases in magnetic performance of these materials by improved processing have been slow but steady. Today high grade materials are available, with the optimum combination of HcJ and (BH) max, for use in automobile starter motor applications.

RARE EARTH PERMANENT MAGNETS

This class of permanent magnet material is based on rare earth - transition metal alloys. Commercial rare earth permanent magnets, based on the $SmCo_5$ intermetallic compound, have been produced since the early 1970's. Shortly after the development of $SmCo_5$ permanent magnets, alloys containing copper as well as the rare earths and cobalt emerged. These were the precipitation hardened family of R (Cu, Co) which eventually led to the development of high energy $Sm(Co\ Cu\ Fe\ Tm)_{7-8}$ magnets (where TM = Zr, Ti or Hf).

During 1983 the commercial production of permanent magnets based on NdFe began. These new materials combine high HcJ with the highest known (BH) max.

Rare Earth permanent magnets are manufactured by a powder metallurgical process similar to that used for Sr / Ba hexaferrite permanent magnets. However, the high reactivity of the rare earths and their alloys and the critical dependence of the magnetic properties on composition requires the effective suppression of contamination during the alloy preparation and subsequent powder processing. In particular, selective oxidation of the rare earth components by O_2 / H_2O must be kept to a minimum through all fine powder handling and high temperature stages.

The main process steps taken during the production of rare earth permanent magnets are shown below:

Alloy preparation by vacuum melting or co - reduction.

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Pre milling <500 μm

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Mill to <4 μm

↓

Composition control and adjustment

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Particle alignment and dry pressing

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Sintering and heat treatment in inert gas or vacuum

↓

Machining

↓

Test, pack and magnetise if required.

All rare earth permanent magnets exhibit high values of HcJ which result in magnetic circuit designs requiring components with short magnetic axes. Such components present particular problems in minimising grinding allowances.

This requires the careful control of pressing conditions and powder dosing in the die cavities, the minimisation of distortion during sintering and heat treatment and the choice of suitable finishing methods. Similarly, because of the high raw material costs, the process control must be such that a zero defect failure rate is guaranteed.

Rare earth permanent magnets are used in a wide range of applications; particularly in those weight - and volume - conscious applications where use is made of their high energy products to achieve miniaturization of the permanent magnet device.

It is impossible here to describe in detail all the many applications in which rare earth permanent magnets and in particular NdFeB, are expected to provide an innovative edge. The major applications are listed on next page and charaterised by their dependence on flux density B.

EXAMPLES OF APPLICATIONS

APPLICATION GROUP	EXAMPLES	SYSTEM FUNCTION PROPORTIONAL TO
ACOUSTIC TRANSDUCERS	LOUDSPEAKERS HEADPHONES TELEPHONE RECEIVERS MICROPHONES PICKUPS	B
PERMANENT MAGNET MOTORS & GENERATORS. ELECTRO-MECHANICAL TRANSDUCERS	D.C. MOTORS E.C. MOTORS SYNCHRONOUS MOTORS STEPPING MOTORS GENERATORS LINEAR MOTORS MOVING-COIL MOTORS TORQUE TRANSMITTERS	B
MAGNETO-MECHANICS	COUPLINGS SEPARATORS ATTACHMENT SYSTEMS MAGNETIC CONVEYORS BEARINGS TRANSPORT SYSTEMS	B^2
MAGNETIC FIELD AND FOCUSSING SYSTEMS	DIPOLES QUADRUPOLES HEXAPOLES UNDULATORS WIGGLERS CIRCULATORS MASS SPECTROMETERS NMR SYSTEM	B

FUTURE DEVELOPMENTS

The different market sectors for both groups of permanent magnet material are all growing rapidly. Improvements in properties are being achieved by a combination of powder processing, microstructural and chemical improvements.

The present disadvantages of NdFeB magnets are all temperature and environmentally related. Alloy developments are being pursued aimed at increasing Curie temperatures, reducing temperature coefficients of coercivity and improving corrosion resistance.