Bonded Magnet Materials and Processing Options

Introduction

Bonded magnets are an important but often overlooked group of products that magnetic circuit and device designers should consider when choosing the optimum permanent magnet type for their specific application need. In their most basic form bonded magnets consist of two components; a hard magnetic powder and a non-magnetic polymer or rubber binder. The powder may be hard ferrite, NdFeB, SmCo, alnico, or mixtures of two or more magnetic powders known as hybrids. In all cases, the powder properties are optimized through processing and chemistry specifically aimed at utilization in a bonded magnet. The binder that holds the magnetic particles in place can produce either a flexible or rigid magnet. Typical binders for flexible magnets are nitrile rubber and vinyl. Binders for rigid magnets include nylon, PPS, polyester, Teflon, and thermoset epoxies. The thermoplastic binders may be formed into sheet via a calendaring or extrusion or formed into various complex shapes using injection molding. Compression bonding almost exclusively combines isotropic NdFeB powders with a thermoset epoxy binder using a uniaxial room temperature pressing process. A major advantage of bonded magnet processing is near net shape manufacturing requiring zero or minimal finishing operations compared to powder or cast metallurgical processes. In addition value added assemblies can be economically produced in a single operation.

Bonded Magnet Processes

There are 4 main processing routes used to manufacture the majority of bonded magnets. These processes are calendering, injection molding, extrusion, and compression bonding.

Calendering is a rolling process for making continuous magnet sheets. It is used for flexible, rubber-based magnets. The granulated compound of ferrite powder and elastomer is fed in the top and through a series of heated rolls. The rolls apply high compressive loads and by applying tension to the sheet as it exits the rollers, a continuous roll of several hundred feet can be formed. In some cases mechanical orientation can be achieved due to the applied pressure and utilizing the plate-like shape of the ferrite particles. Typical sheet thicknesses are from 0.012 to 0.250 inch. Hard magnetic powders are normally ferrite though some NdFeB and ferrite/NdFeB hybrids are available. A typical calendaring process is shown in Figure 1 below:

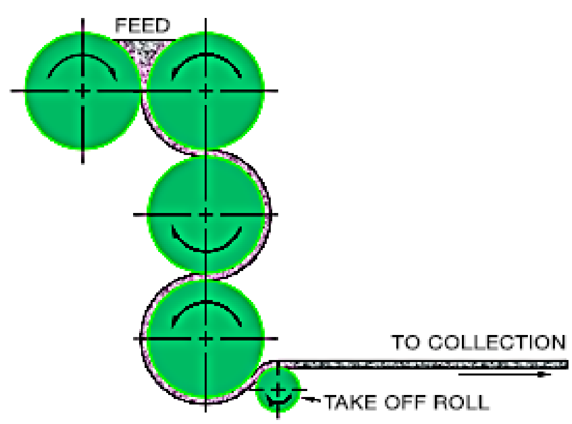

Figure 1

Injection molding is the process of injecting a molten, highly filled thermoplastic compound into mold cavities where it is allowed to cool and solidify. Ferrite and NdFeB powders are commonly used as the magnetic powder in the compound. Typically multi-cavity tooling is used to achieve high volume output and productivity. Complex shaped magnets can be formed by this process together with multicomponent assemblies by in

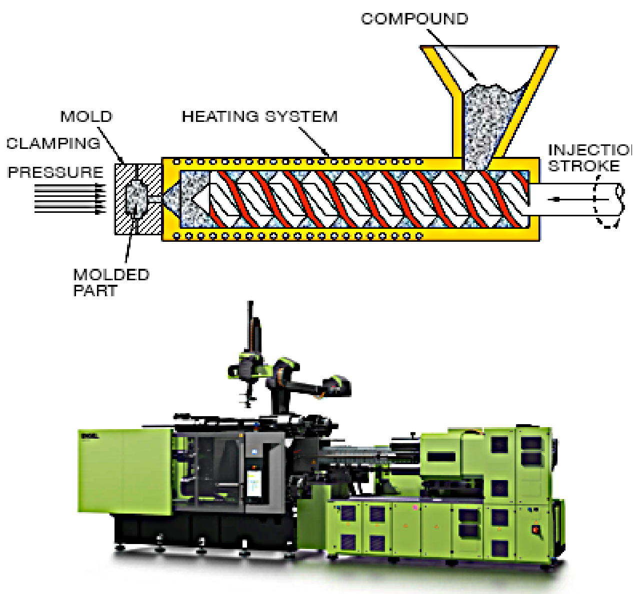

Figure 2

sert and over molding techniques. Standard magnetic powder loadings are around 65 volume %. Figure 2 below shows a typical injection molding process.

The raw material used in the **extrusion process** is similar to the compound used in calendering. The extrusion screw works against a heated barrel to push the compound through a heated die at high pressure. The resulting continuous strip of material is collected, either on a spool, cut sheet is stacked, or strip is cut into pieces of specific length. The cross-section profile of the strip must remain the same along the length of the extrusion. It should be noted that since both ferrites and NdFeB powders are very abrasive special wear resistant coatings are used in both injection molding and extrusion tooling. Figure 3 shows the process used for extruded bonded magnets.

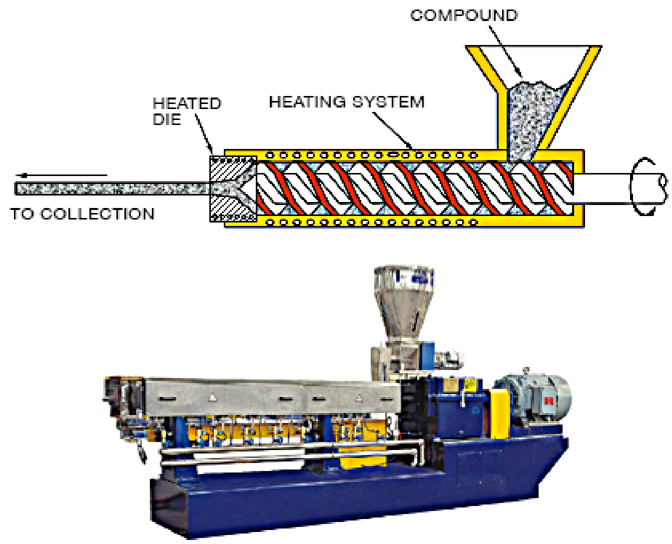

Figure 3

The fourth manufacturing process is **compression bonding**. Optimum performance is obtained by processing the NdFeB powder through a powder refinement step and liquid encapsulating process to coat each particle with a thin film of thermoset epoxy and hardener and other additives e.g. die wall lubricant. The encapsulated powder is fed into a press cavity and compacted under pressures of about 6 tonnes/cm2. The compacted magnet is then cured at temperatures of about 150–175 °C. One major advantage of compression bonding is that the magnetic loading can be as high as 85% by volume, resulting in higher flux densities than calendered, injection molded, and extruded magnets. Dimensional tolerances are equivalent to injection molded products, making secondary operations generally unnecessary. The development of compression bonded NdFeB with maximum energy products of 10 MGOe and higher along with net shape capability of arcs and cylinder shapes have found numerous applications in brushless DC motors. Also the capability to form long axial length, thin wall cylinders combined with the relative ease of multipole magnetizing has led to compression bonded NdFeB magnets being used in high volume HDD spindle motors as well as other BLDC motor applications. The typical compression bonding process is show in Figure 4 below.

A major advantage of isotropic NdFeB magnetic

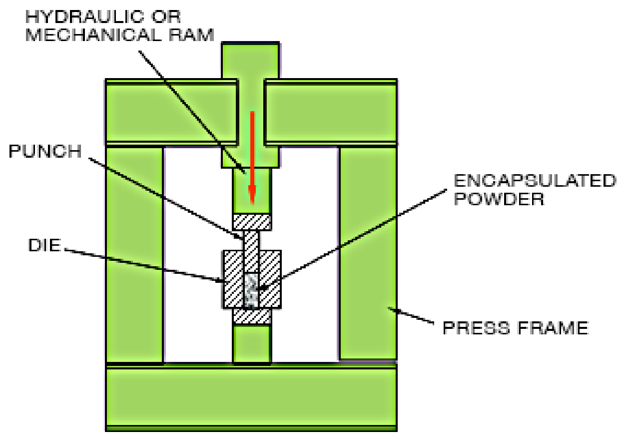

Figure 4

powders is that no aligning field is required during forming process (injection molding or compression bonding), simplifying fabrication and since there is no residual magnetization to attract ferromagnetic particles to the magnets, enhancing cleanliness during subsequent handling and assembly operations.

Injection molding versus compression bonding

Injection Molding

Pluses
- Complex forms with good geometrical tolerances
- Multi-cavity tooling
- Over and insert molding

Minuses
- Expensive tooling
- Lower magnetics (66% volume loading of magnetic powders)
- NdFeB and ferrite

Compression Bonding

Pluses
- Thin wall, large L/D ratio rings
- Simple low cost tooling
- Higher magnetics (75% volume loading of magnetic powder)

Minuses
- Simple geometrics
- Value added operations during pressing very difficult
- NdFeb only

Future Developments

It is interesting to note that while anisotropic powders based on both NdFeB and SmFeN alloys have been available for over a decade they appear to have only had a minor impact on bonded magnet applications. One significant drawback of both types of powder is their thermal stability and low maximum operating temperature capabilities. Also that requirement to apply an orienting field during the forming operation adds to the complexity of tooling and increases the magnet processing costs.

Current grades of compression bonded NdFeB magnets are limited to about 11 MGOe using the isotropic powders currently available. The BH-max in a compression bonded isotropic NdFeB magnet is only influenced by two factors.

These are:

1. Volume fraction of magnetic phase in the magnet – typically measured by the density of the magnet. Today's approach is one of brute force i.e. increasing the pressing pressure which requires special press construction and tooling materials. However, work is underway to improve the compressibility of powders and therefore

achieve high densities with moderate pressing pressures. It is also important to improve the flowabilty of powders to enable even thinner wall die cavities to be filled uniformly during the pressing operation.

2. Magnetic powder remanence (Br) – the goal is to Increase isotropic Br of powders while maintaining sufficient coercivity (Hci) to have linear demagnetization characteristic at the application temperature.

Another exciting processing technology that has the potential to revolutionize the production of bonded magnets is 3D printing or additive manufacturing. MAI has teamed with researchers at Oak Ridge National Laboratories (ORNL). The technical objective of the proposal is to fabricate net shape isotropic NdFeB bonded magnets utilizing additive manufacturing technologies at ORNL. The goal is to form complex shapes of both thermoplastic and thermoset bonded magnets without expensive tooling and minimal wasted material.

Comparison of the bonded and fully dense (sintered) magnets

Bonded

- Excellent geometric tolerances with minimal or no secondary operations
- Good mechanical properties
- Comples shapes
- Insert/overmolding of sub assemblies
- Higher electrical resistivity
- Multipole magnetization
- Tailored flux output for given size/shape magnet

Sintered

- Highest flux output
- Higher operating temperature

Conclusions

Bonded magnets are a diverse and versatile contributor to the portfolio of permanent magnet materials available to device designers. They offer many unique advantages in both product form and value added assembly capabilities. They find application in a wide range of devices and markets. Future innovation of both processing and materials will provided more benefits to designers and stimulate even higher growth and market penetration.

About Magnet Applications, Inc. (MAI)

MAI (www.magnetapplications.com) is located in DuBois, PA and is one of the largest North American manufacturers of injection molded (both ferrite and NdFeB) and compression bonded NdFeB magnets. In addition MAI supplies a full range of permanent magnet products and technical assemblies supported by application and sales engineering throughout North America.

They are part of the Bunting Magnetics Group (www.buntingmagnetics.com). Bunting Magnetics is a family-owned group of companies manufacturing products which serve global markets and include a broad range of magnetic materials and components, magnetic separation systems, material handling equipment, metal detection equipment, magnetic cylinders for the printing industry, bonded magnets, and technical assemblies.

MAGNET APPLICATIONS®

A Bunting® Magnetics Company

12 Industrial Drive • DuBois, PA • 15801 USA
800-437-8890 • (+1) 814-375-9145 • Fax (+1) 814-375-9146
Email: Sales@MagnetUS.com
www.MagnetApplications.com