Heavy rare earth reduction

The production of permanent sintered NdFeB magnets can help reduce the need to mine for heavy rare earth elements in magnetic alloys.

JLMAG Rare-Earth (JLMAG) is one of the biggest manufacturers of sintered NdFeB magnets in the world, with an annual capacity of 6,000 tons. This will increase to 10,000 tons within the next two years as the Chinese company ramps up production. Further more, as JLMAG supplies to green applications, the company also plans to start contributing to the cradle-to-cradle production of magnets (see Figure 1).

Two mining organizations of rare earth elements are shareholders in JLMAG, which has direct access to the key metallic elements that are needed for the production of sintered NdFeB magnets. This includes the refinery of ores into oxides and oxides into pure metals.

Moreover, these same companies also offer a solution to recycle magnet scrap, production waste and end-of-life magnets. A major advantage is the overall reduction of production costs. Another advantage relates to the cradle-to-cradle concept: the reduction or even full elimination of the need to mine for new raw materials for new production. This means that end-of-life magnets can be disassembled and reworked via the refineries, with magnet production of new magnets being realized. As such, it is highly recommended to develop magnet application designs that can be disassembled easily (design for recycling). The production of sintered NdFeB magnets also contributes to the cradle-to-cradle concept with an active reduction program for heavy rare earth elements (dysprosium and terbium).

Heavy rare earth elements such as dysprosium and terbium are needed to reach high intrinsic coercivity (HcJ) levels. High HcJ is needed to provide sufficient resistance to demagnetization that’s caused by high temperature and/or high demagnetization fields. Electric motors for hybrid and electric vehicles are examples in which strong demagnetizing fields may occur in combination with high temperatures. Other examples are mid- or high-speed gearbox wind power generators that use permanent magnets.
Compared to so-called light rare earths such as neodymium and prasodymium, heavy rare earth elements are really rare. Most dysprosium and terbium is mined in China, while neodymium and prasodymium are abundant in other locations outside of China. The reduced availability has drastic consequences regarding pricing. Moreover, the future supply of dysprosium and terbium may not be fully guaranteed as future demand and availability may not be balanced.

**Raw material formulation optimization**

These doubts over availability mean it makes sense to reduce the need of heavy rare earth elements. There are three major ways to accomplish this: new material development; design optimization; and process variation reduction. JLMAG has been able to reduce the content of dysprosium and terbium in magnetic alloys using the process and recipe of raw material formulation optimization.

Sintered NdFeB magnets consist of small grains with Nd2Fe14B crystals that are covered with a rich Nd phase. Optimization of the rich Nd phase is crucial to reducing the need for heavy rare earth materials (Figure 2). This rich phase can be optimized either by changing raw materials (such as usage of trace elements) or process improvements (adjustment during the melting and sintering processes). However, the average grain sizes and homogeneity of grain sizes has a strong relationship with \( H_{cJ} \). Smaller grains tend to increase \( H_{cJ} \) with the same raw material formulation. Final grain sizes are mainly determined by the pulverization of strip cast flakes into powder (also known as the jetmilling process). Recently, JLMAG has been able to reduce the average powder particle size and its variation (see Figure 3).

Figure 4 gives an example of the increase of \( H_{cJ} \) (typically 80kA/m at room temperature) with the same raw material formulation for an optimized jetmilling process. This process and formulation optimizations have resulted in many heavy rare earth free magnetic alloys.

The development of the newest VH alloys has been a positive side-effect of the heavy rare earth reduction program. The VH grades reach \( H_{cJ} \) levels >3,200kA/m at room temperature suitable for applications of typically <250°C. Old material formulation has been combined with the newest process technology to guarantee these levels.

Critical review of current and old magnet designs often offers changes for heavy rare earth reduction as well. Overdesign of \( H_{cJ} \) leads to overdesign of magnetic alloys. In many cases, a slight reduction of temperature or reduction of \( H_{cJ} \) has resulted in a significant decrease of heavy rare earth elements needed in the magnetic alloy.

The relationship between irreversible flux losses and \( H_{cJ} \) is very important in order to know the potential for demagnetization at certain temperatures and working points. Figure 5 gives an overview of a flux loss test. Such findings prompt discussions as to the real need of \( H_{cJ} \) and heavy rare earth elements.

Besides measurements, JLMAG offers accurate and state-of-the-art finite element analysis to match demagnetization fields with the right demagnetization properties of magnetic alloys. In addition, JLMAG also uses process optimization tools (six sigma, lean manufacturing principles) to reduce the variation of \( H_{cJ} \). This offers good potential to reduce the content of heavy rare earth elements because the nominal value of \( H_{cJ} \) can be reduced when the variation is reduced as well (Figure 6). The combination of these efforts to reduce heavy rare earths has resulted in heavy rare earth free N, M and most H grades. Other heavy rare earth free grades are currently under development.