## Production of NdFeB permanent magnets at MIMplus

MIMplus does not only develop processes for already available MIM materials, but also new materials for the MIM process. One major example are the MIM permanent magnets based on NdFeB-type alloys that MIMplus Technologies developed in the last recent years.

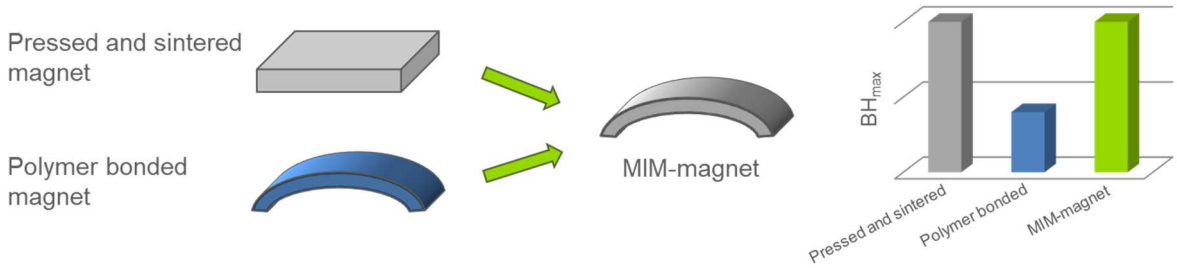
The market demand for strong permanent magnets, especially needed for electric motors of electric vehicles, new sensors or electronics, increased during the last years strongly. It has a strong impact on the dependency of the European economy on Chinese resources needed for production of permanent magnets. The strongest magnets, the so-called super-magnets based on NdFeB, consist of ~30 wt% of so-called Rare Earth elements which are mainly mined in China. Fractions of the world-wide demand are mined in other countries. China provides 98% of the EU's demand of RE elements [https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0474]. Especially for the heavy rare earth elements, like Dy and Tb, China has a monopoly on its mining, since the only sources world-wide are located there.

As a consequence, the European Union classified the RE elements as critical with a high economic importance and simultaneously a high supply risk. 28 further resources are classified as highly critical for the EU and are on the list of critical resources [Source: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0474].
Having a closer look on the recycling rate of RE elements, the recycling contribution to the Nd demand within EU is only around 1% compared to ~50% for other metals like iron, zinc, platinum [Source: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0474]. The low recycling rate and the high supply risk were two main reasons for the European Union to intensify research in Europe in this field. Several funded research projects dealing with the recycling of RE elements are located unter the roof of Horizon 2020, a flagship initiative aimed at securing Europe's global competitiveness.

## Participation to public funded research projects

The increasing demand of complex permanent magnets as well as the financial support from the European Union led MIMplus (legal successor of OBE Ohnmacht & Baumgärtner GmbH & Co. KG) to focus on the development of a recycling and a production process for MIM NdFeB permanent magnets. Since several years now MIMplus works intensively on the whole process chain from recycling material to new MIM magnets with high performance.

The main idea of metal injection molded permanent magnets is to use a combination of the advantages of the two state of the art technologies for producing magnets: press-and-sintered magnets and polymer bonded magnets. The combination of both technologies will allow the production of complex MIM permanent magnets that have a high energy product $BH_{max}$ and simultaneously a complexity of shape, that can be only realized by cost-intensive machining of conventional produced press-and-sinter magnets, so far. The magnetic properties of MIM magnets are well comparable to that of press-and-sinter magnets.



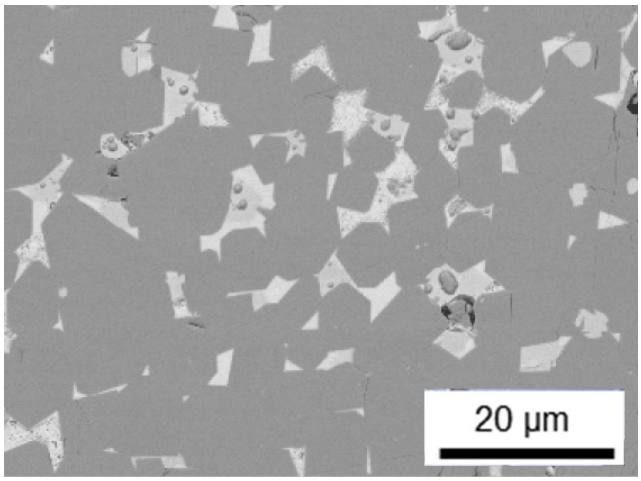

*1: The idea of MIM magnets: Combination of the two state-of-the-art production technologies for NdFeB magnets: press-and-sintering and polymer bonding.*

Starting in 2015, MIMplus participated as one of 14 European partners the European project REProMag (2015 – 2018) with the goal to produce 100% recycled permanent magnets via the MIM route. In 2017 MIMplus (legal successor of OBE Ohnmacht & Baumgärtner GmbH) won the German Innovation Award for Raw Material Efficiency as a partner in the REProMag consortium.

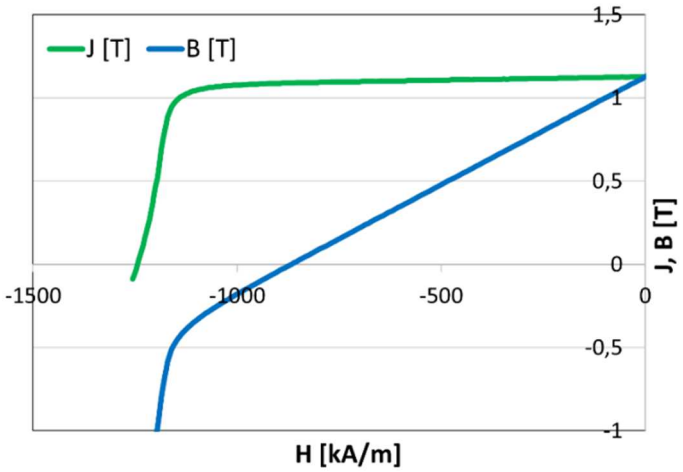
After the success of this project MIMplus continued the research on MIM permanent magnets with two follow-up projects: MaXycle (2018 – 2021) and SUSMAGPRO (2019 – 2023).

MaXycle focusses on the development of a labeling strategy to facilitate recycling of RE containing assemblies. In the scope of this project MIMplus continued its recycling and production process at laboratory scale.

The second project SUSMAGPRO was started as a scale-up project with the idea to realize four magnet recycling plants within whole Europe. In the scope of this project MIMplus has built up a magnet recycling pilot plant at its facilities in Ispringen, Germany. It includes the recycling of end-of-life magnets, powder preparation, feedstock production, debinding and sintering of MIM NdFeB magnets.




*2: Typical microstructure of a MIM NdFeB permanent magnet.*

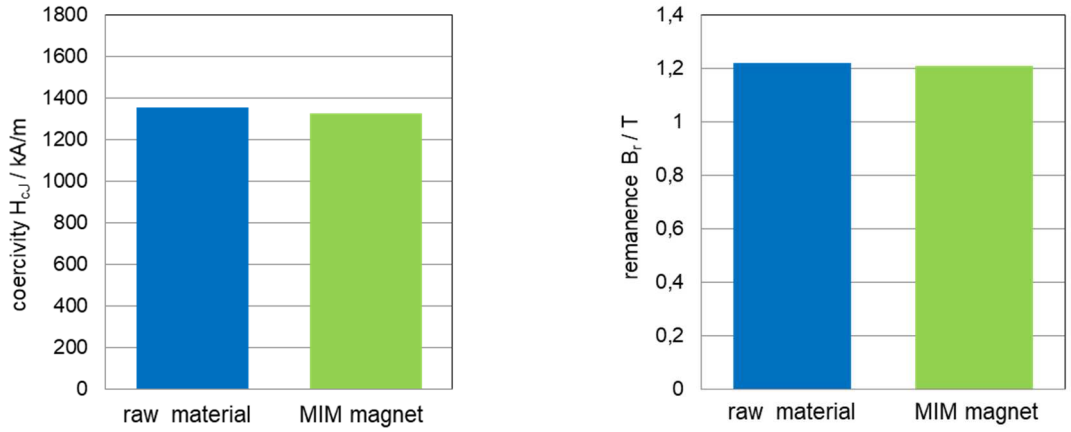



*3: Typical hysteresis loop of a MIM magnet.*

**Breakthrough in magnet production in 2021**

After more than 6 years of intensive research MIMplus had a breakthrough in the production process of MIM permanent magnets in 2021. The company has developed a stable production process in pilot scale for production of MIM permanent magnets with properties, only known from press-and-sinter magnets so far.

MIM magnets made from recycled material can achieve the magnetic performance of the end-of-life magnets used as raw material. The magnetic performance, i.e. coercivity $H_{cJ}$ and remanence $B_r$, are >98 % of the raw material. Through ongoing research across the whole process chain it might be possible to reach up to 100% of the performance of the raw material, according to MIMplus.




*4: Magnetic properties of a MIM-magnet from recycling material compared to the used raw material (end-of-life magnets from a wind turbine).*

For reaching this goal a large process know-how for powder and feedstock handling was developed, which is only one part for a good and stable manufacturing process. Lots of efforts were invested into the injection molding process, here especially into the tool design. Of course also the following process steps, especially sintering are of high complexity and needed intensive research.

This innovative development opens up new markets for the MIM process in electro mobility, for miniaturized electric motors such as those used in medical technology or for special applications in sensor technology and electronics. MIM magnets from MIMplus Technologies can be produced from recycled end-of-life magnets or new material to allow a cradle-to-cradle approach for its customers.


*5: MIM magnet in hysteresis graph for magnetic characterization.*