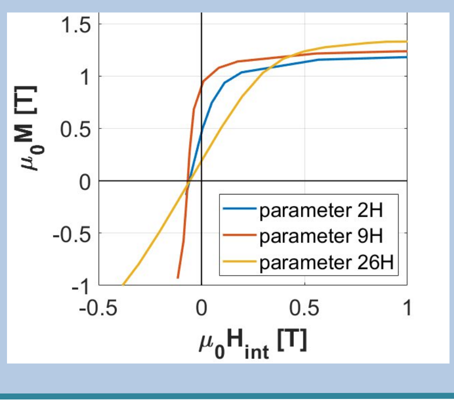

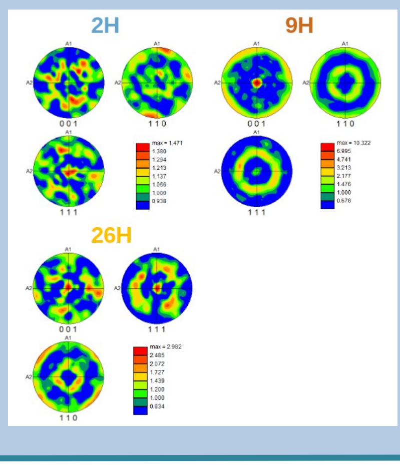

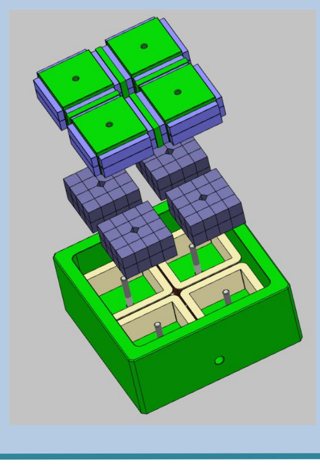

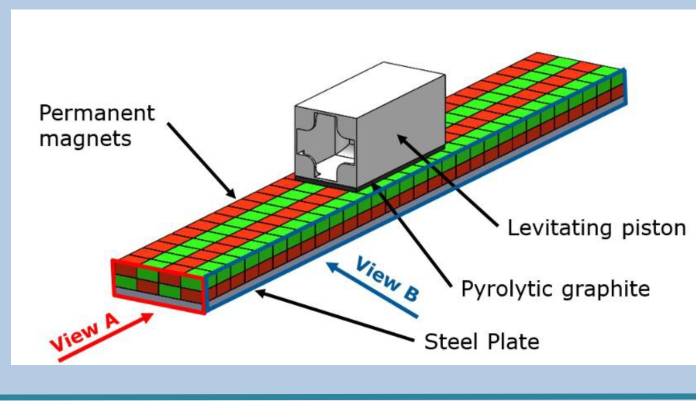

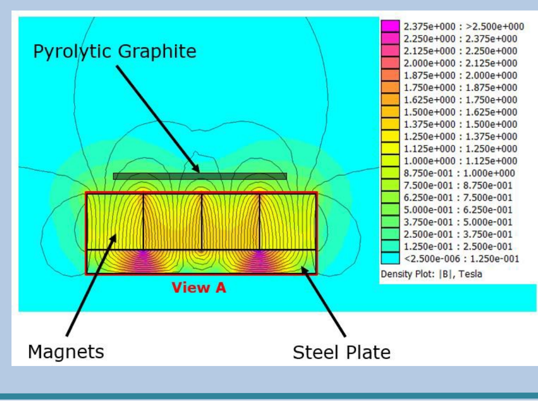

Additive manufacturing of magnetic materials:

Simulation of a circular economy in a European environment

Motivation

The AddMag project focuses on advancing a European circular economy by developing novel processes for recycling and production of permanent magnets:

1. **Recycling and Resource Efficiency:** Nd and Co are listed as critical raw materials by the European Commission. AddMag aims to both advance the recycling process for end- of -life Nd-Fe-B magnets and to reduce the Co content in Fe-Co based permanent magnets while maintaining sufficient magnetic properties
2. **Additive Manufacturing:** Additive manufacturing can play a key role in efficient resource managing as the inherent possibility to produce intricate structures opens the possibility for an improved magnet topology and techniques like in-situ alloying allow for the production of functionally gradated permanent magnets while maintaining a high part-to- waste ratio
3. **Application and Innovation:** The permanent magnets produced in this way can be tested for potential use in automotive sensors and valves as well as magnetic lifting systems with the aim of demonstrating their applicability in novel green energy solutions which will contribute in advancing the EU net zero goals.

Key Findings:

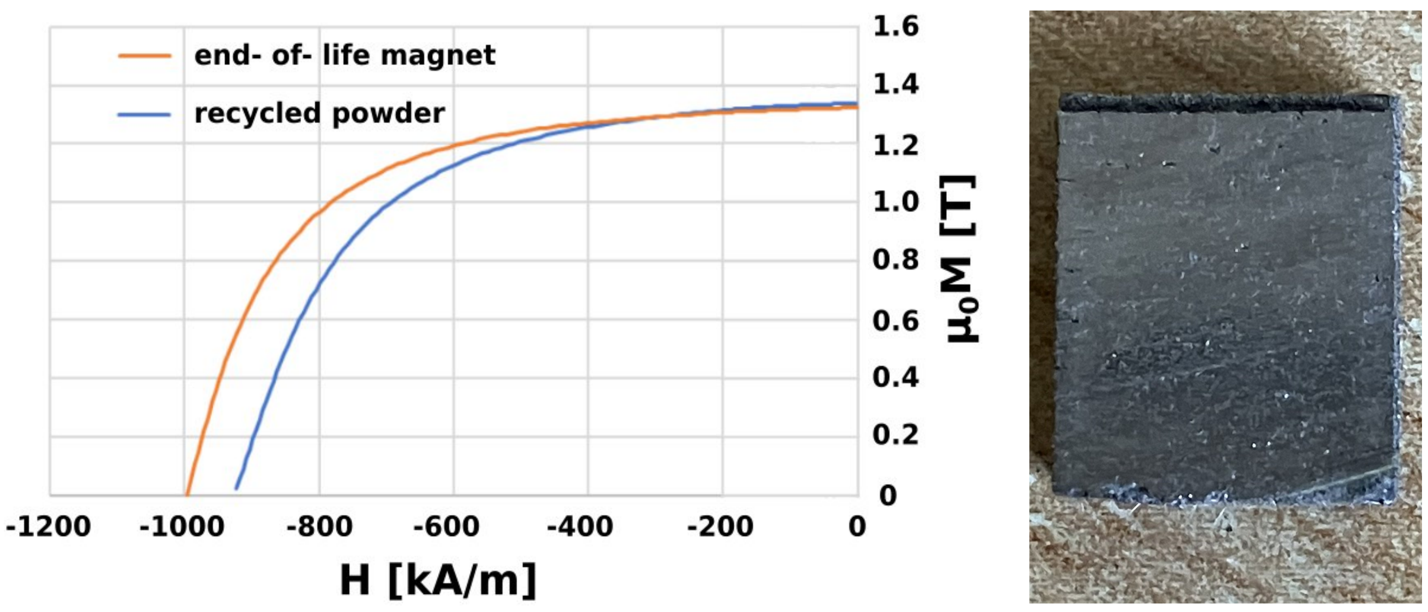

Fig.1: *A high degree of optimisation of the recycling process of end- of life magnets allowed for the production of high quality powders with similar oxygen (930ppm|1025ppm) and hydrogen contents (5ppm|<5ppm) in the end-of-life magnet and the recycled powders. A high quality powder allowed the production of dense AM Nd-Fe-B magnets with the in- situ grain boundary infiltration process*

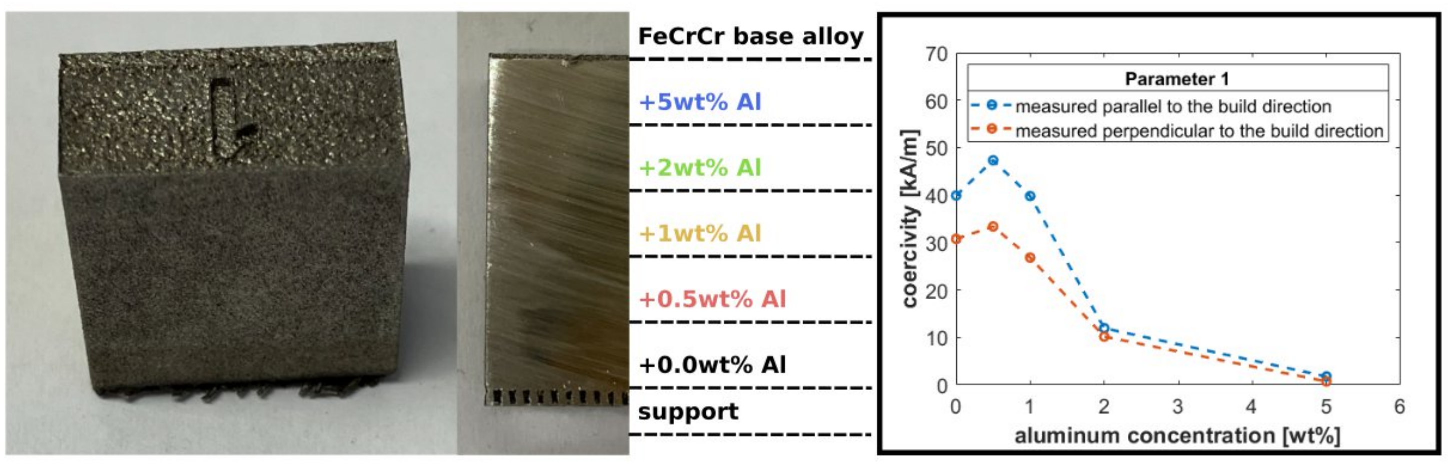

Fig.2: An advanced understanding of the printing process in Fe-Cr-Co allowed the production of functionally graded magnetic structures with different magnetic properties parallel to the building direction

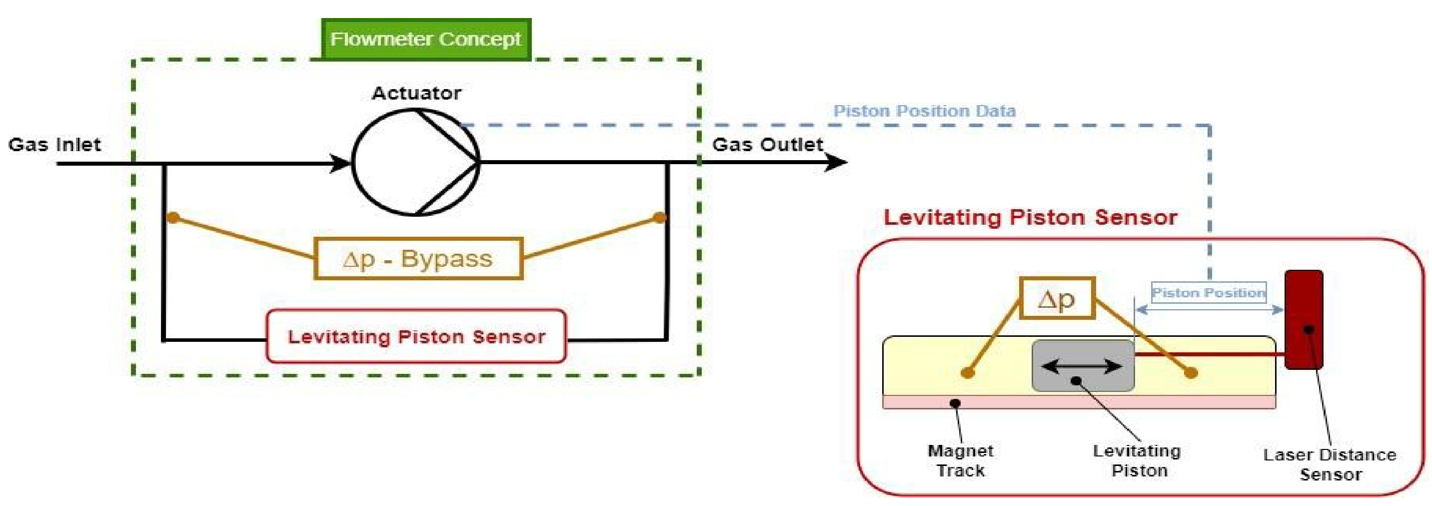

Fig.3: *Different use cases were designed to show the applicability of additive manufactured permanent magnets: Concept of a flow meter based on a magnetically levitating piston sensor*

Abstract

The rapid evolution of additive manufacturing (AM) presents many novel opportunities for the development of advanced magnetic materials. In this project, we explored the potential of AM techniques to produce three types of magnetic materials: Fe-Cr-Co, Al-Ni-Co, and Nd-Fe-B. Our goal was to understand how additive manufacturing can influence magnetic properties and to assess the practical applications of 3D printed magnets.

Our investigation was structured into three main branches:

1. **Powder Manufacturing:** We developed and optimized the processes for producing high-quality powders suitable for AM. This involved analyzing particle morphology, size distribution, and composition to ensure the powders met stringent performance criteria.
2. **Additive Manufacturing:** Utilizing Laser Powder Bed Fusion (LPBF) and Material Extrusion (MEX) techniques, we successfully fabricated complex magnetic structures. Through extensive experimentation, we identified key printing parameters and post-processing conditions that influenced the magnetic properties of the printed materials.
3. **Application Development (Use Cases):** We assessed the practical usability of our 3D printed magnets in real-world applications including magnetic lifting systems, sensor technologies and valve mechanisms, where our predefined objectives were well met.

Impact and Takeaway:

The project aimed at enhancing European independence in magnet production by developing innovative processes using recycled materials with the final goal of reducing the carbon footprint and promoting sustainability. It advances technology from TRL 2 to 3 for the production of complex magnetic parts and their application in green energy technology. Key achievements include dramatically improving the recycling process for Nd-Fe-B powder from end-of-life magnets, improving the printing process and demonstrating a proof of concept for the in-situ grain boundary infiltration technique. The project also facilitated the creation of functionally graded Fe-Cr-Co magnet structures facilitated by a deeper understanding of the influence of process parameters and alloying conditions on the magnetic properties in Fe-Cr-Co. Furthermore, the project showcased three successful use cases for additive manufactured magnets. The research highlights the potential of additive manufacturing (AM) in creating functional magnetic components, emphasising the importance of careful consideration of processing parameters to meet specific application requirements. The integration of circular economy principles into magnet production can foster a sustainable future for the industry.

Acknowledgements

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