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THE NEXT LEVEL

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Additive Manufacturing of Magnetic Materials for a New Generation of Electrical Drives

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Application fields

Large electric drives

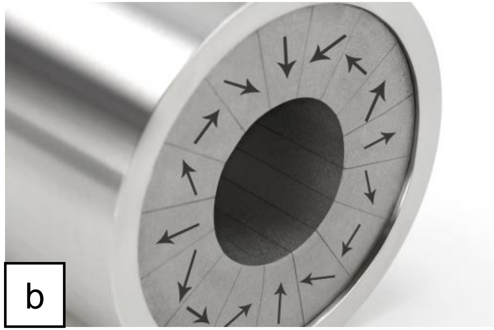
Process industry

Mobility

Conventional designs for magnets

- Limited possibilities for complex designs
- Complex and manual assembly
- Tight fittings

a



b

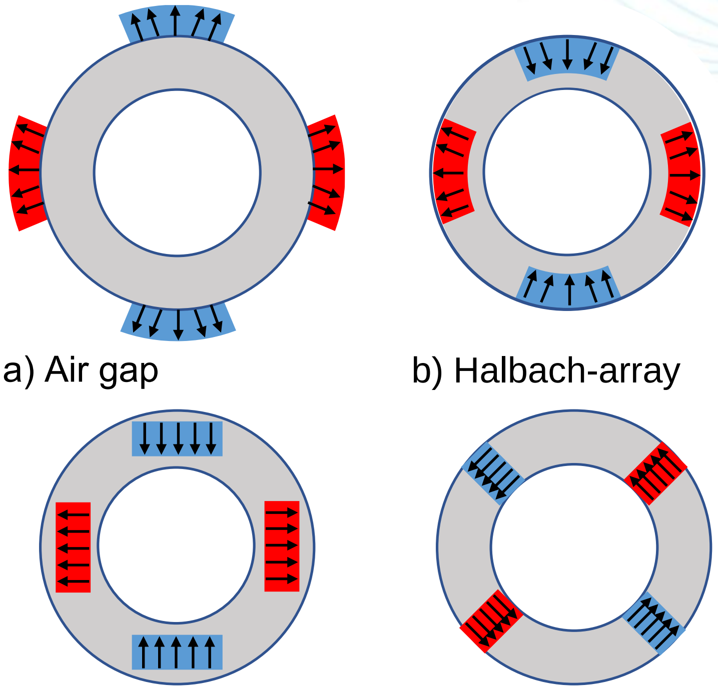
c

a) Magnet block for wind turbine
b) Small sectioned Halbach array
c) Bonded magnet assembly

Source: Vacuumschmelze©

Research goal, possibility of AM

- New designs with flow barriers
- Magnetic flux concentration
- Internal cooling systems
- Simplification of manufacturing and magnetization
- Flexibility of manufacturing
- Using optimized magnetizing patterns for better efficacy



a) Air gap

b) Halbach-array

c) Buried magnets

d) Flux concentration

Applications and the AM process investigated

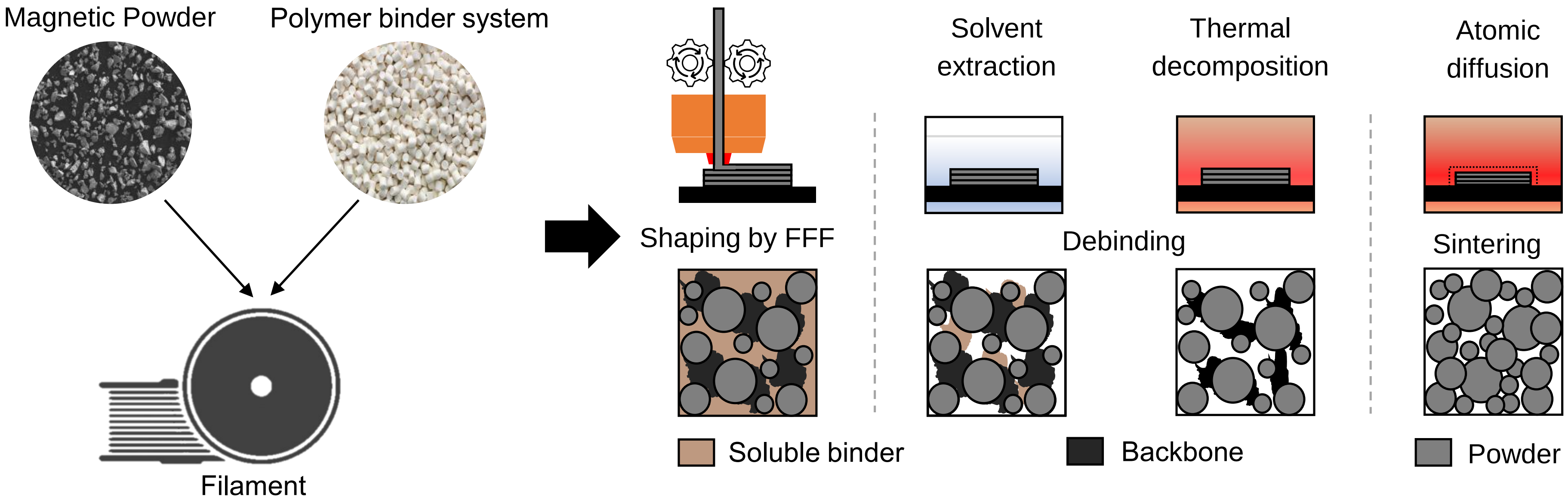
Fused Filament Fabrication

Cold Spray

Source: https://drohne-quadrocopter.de/dji-f450/ Siemens ©

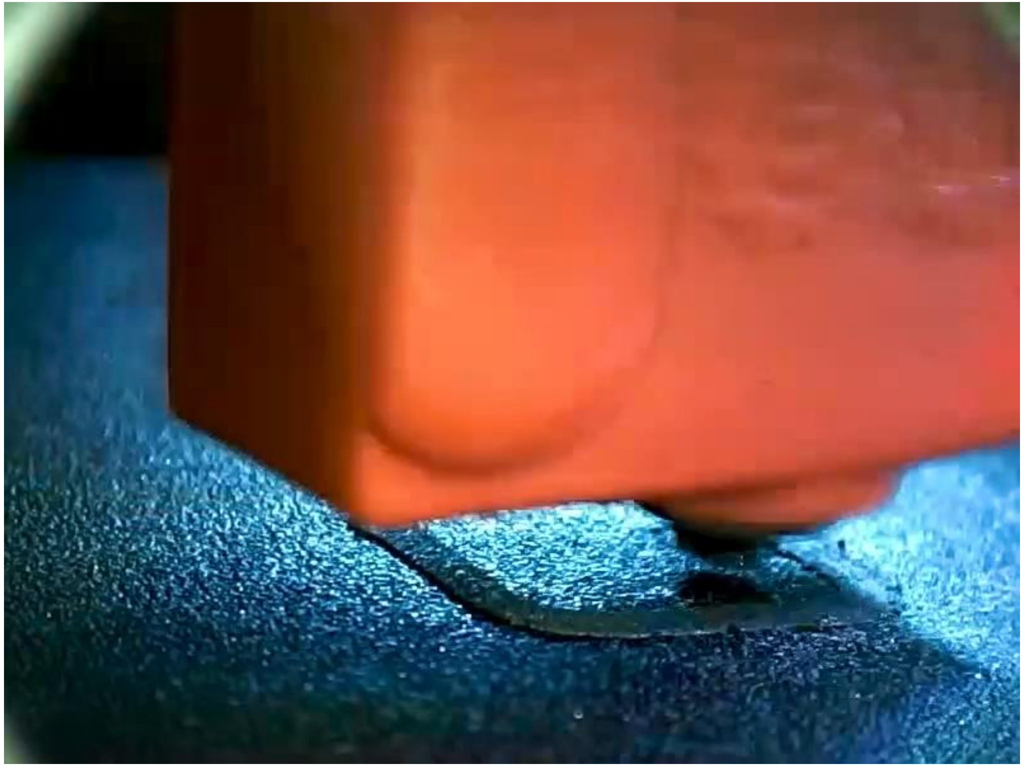
Fused Filament Fabrication (FFF)

Shaping, debinding, and sintering (SDS)



Source: https://busscorp.com/de/industrien/thermoplastische-elastomere/

Printing process



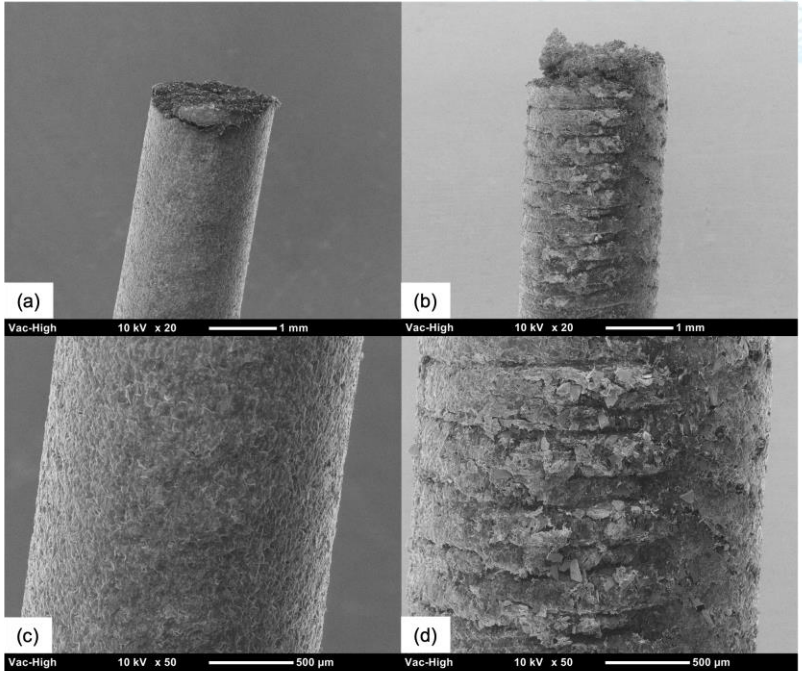
Magnetic Filament and challenges during the printing process

Magnetic Filament

- Investigated materials: NdFeB (55 vol%), SmCo (55 vol%), SrFeO (50 vol%)
- Polymer binder: TPE (main binder) + grafted polyolefin (backbone)

Challenges

- Processing problems with highly filled polymers
  - Extrusion problems
  - Filament abrasion, deformation, buckling
  - Cooling problems
- Generation of magnetic anisotropy

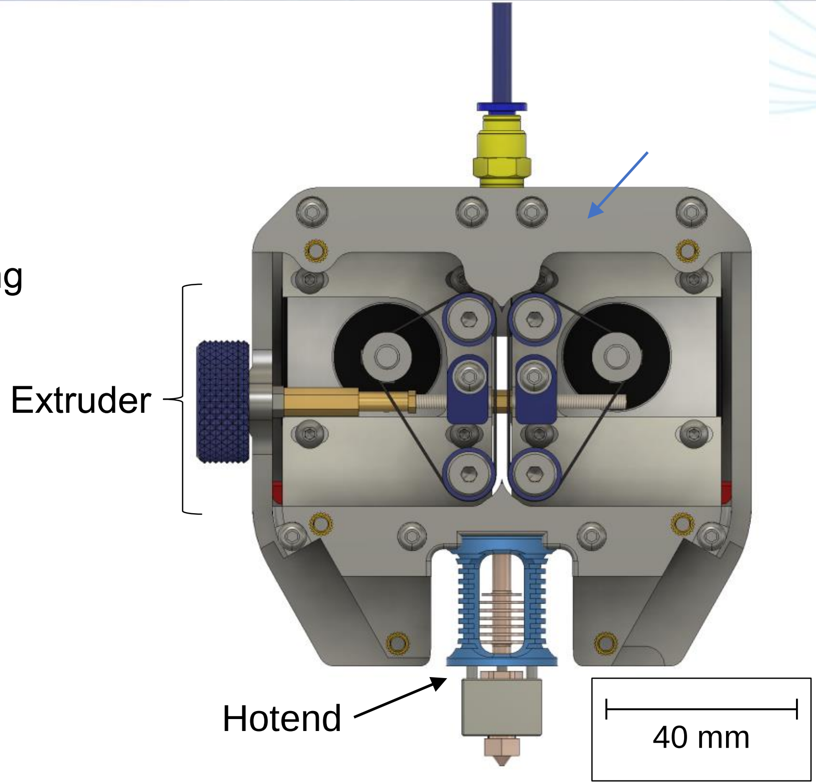


SEM Image: NdFeB-Filament (45µm, 55 vol %):
(a) and (c) before Extrusion (Flexion Extruder),
(b) and (d) after Extrusion

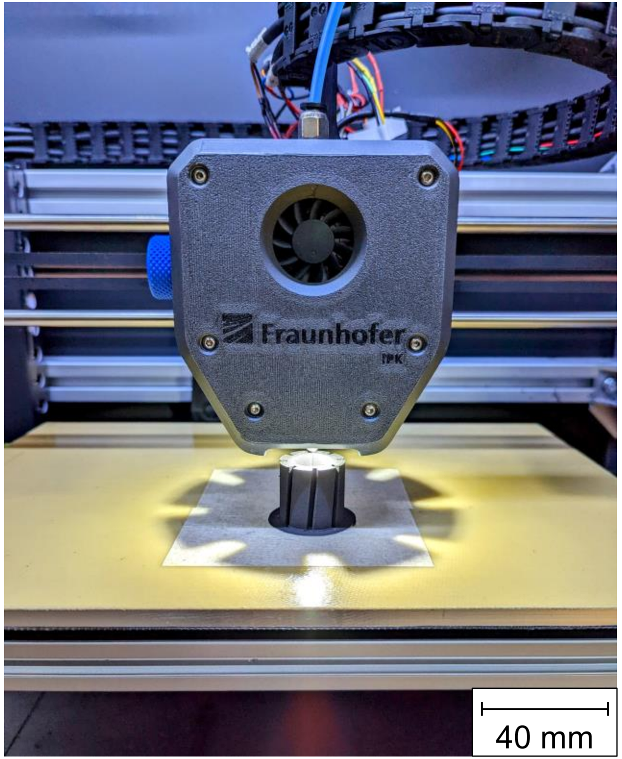
Magnetic Filament and challenges during the printing process

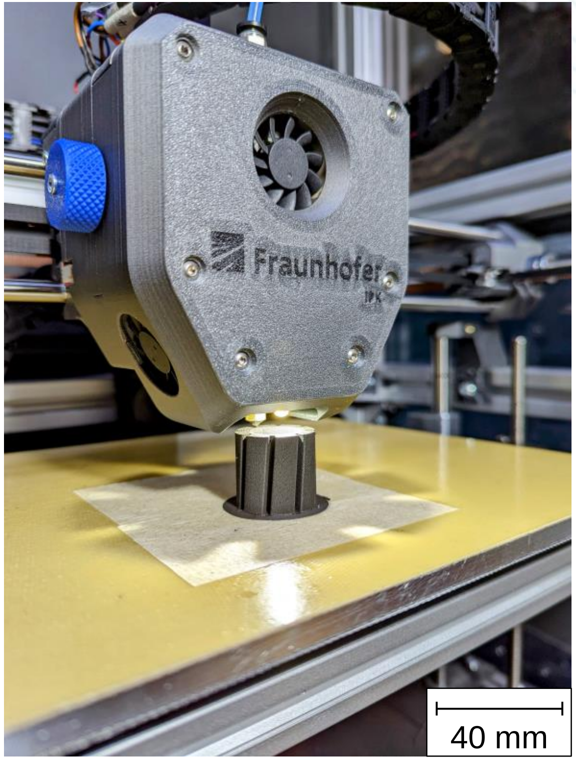
Development of an FFF-printhead for the processing of highly filled polymers

- Damage free filament extrusion
- High performance part and filament cooling
- Short conveying distance
- High process reliability



Printing process of a magnetic rotor

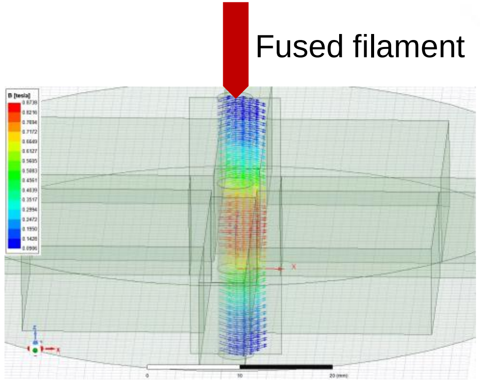




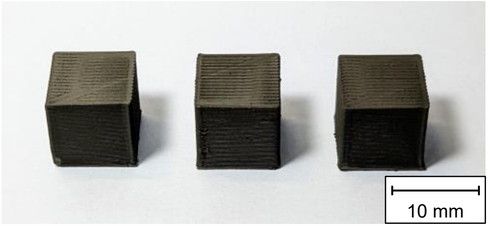
Generation of magnetic anisotropy during printing process

Concept for the generation of magnetic anisotropy in the green part

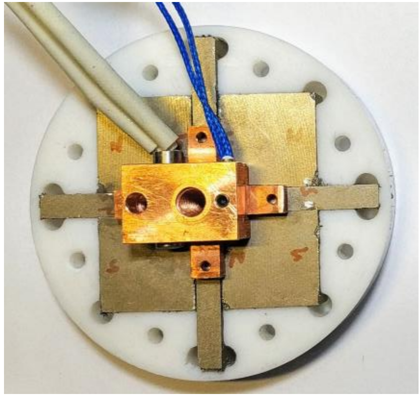
- Alignment of the magnetic through a homogeneous magnetic field inside of the melting zone
- Generation of a strong magfnetic field with a SmCo Halbach array (B ≈ 0.9 T)
- Investigated orientations: axial and transversal print directions
- Test geometry: cube (10 x 10 x 10 mm^3)



Simulation of magnetic field



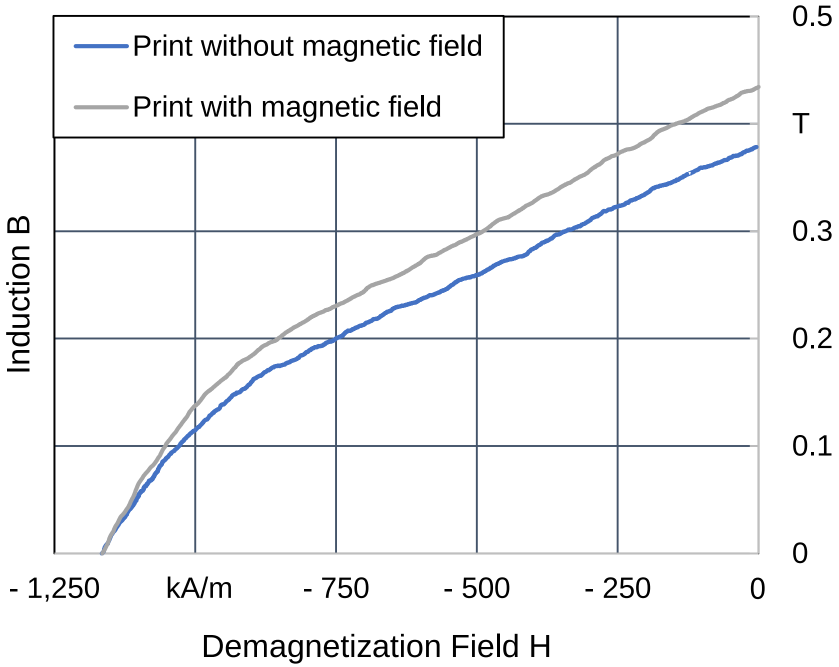
Printed specimen



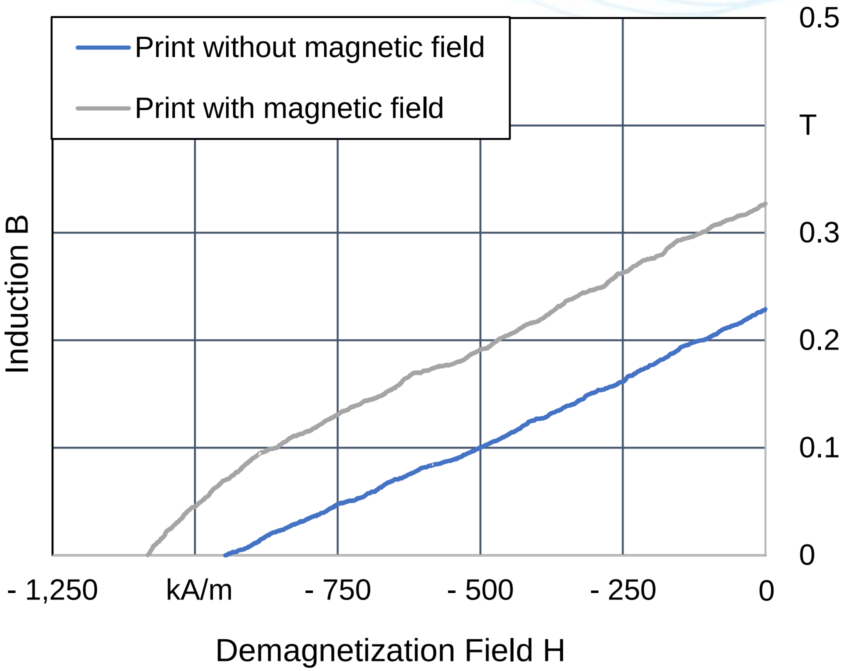
Halbach array nozzle

Comparison printing with magnetic field and without magnetic field

Hysteresis in axial print direction

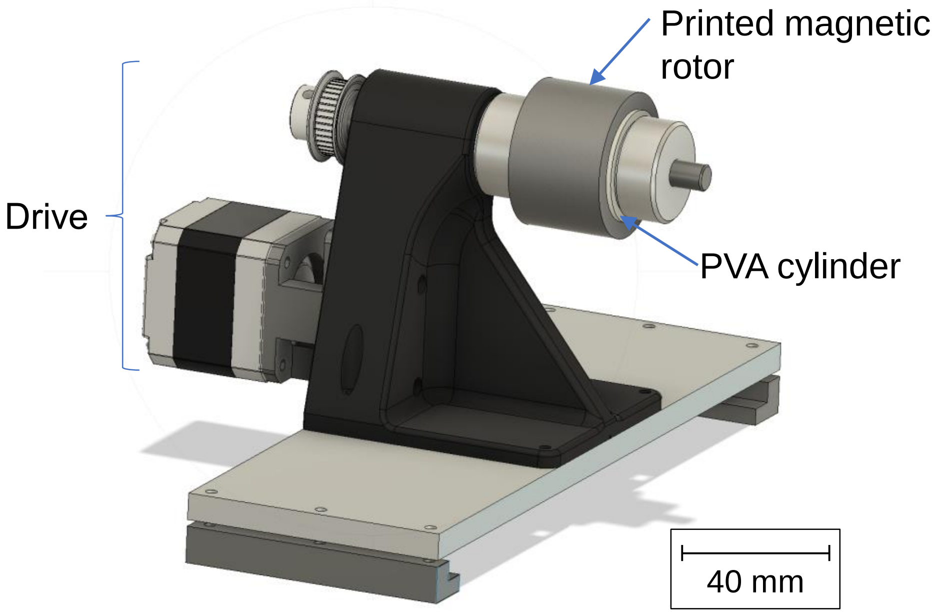


Hysteresis in transversal print direction



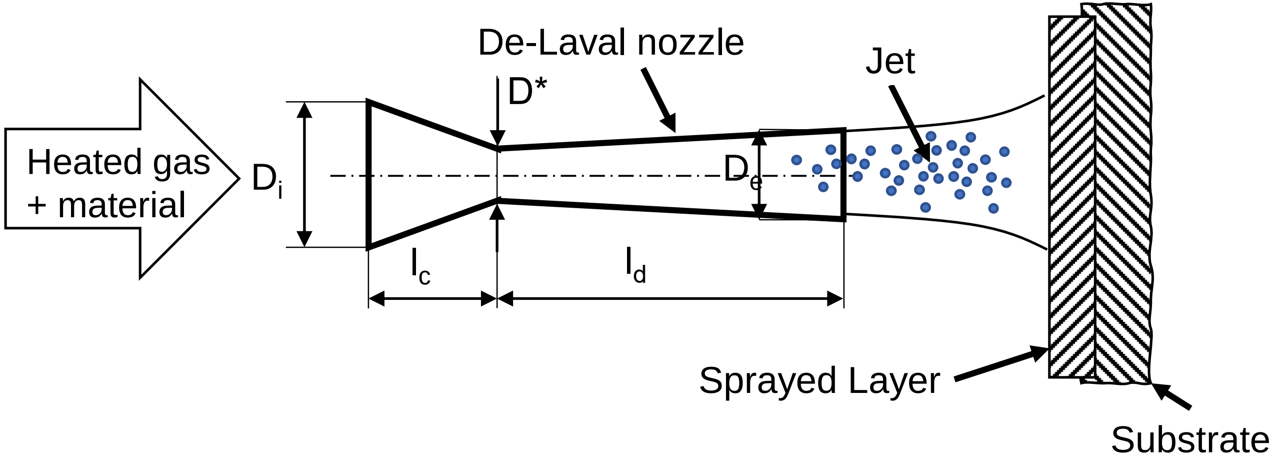
Outlook

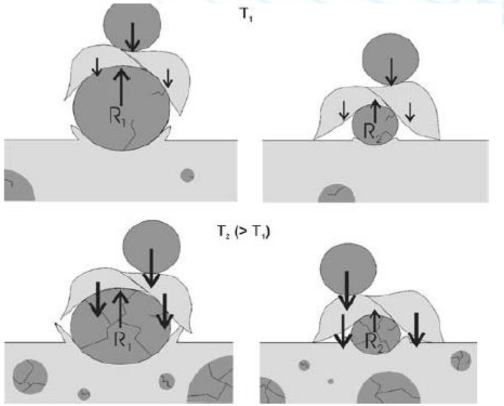
- Increase hard magnetic properties
- Increase anisotropy
- Developing the sintering process
- Investigate polymer bonded magnets
- Using optimized magnetic patterns for better efficiency (Halbach array, topology optimization, …)
- Printing a anisotropic magnetic rotor with a rotational print bed



Cold Spray

Introduction Cold Spray



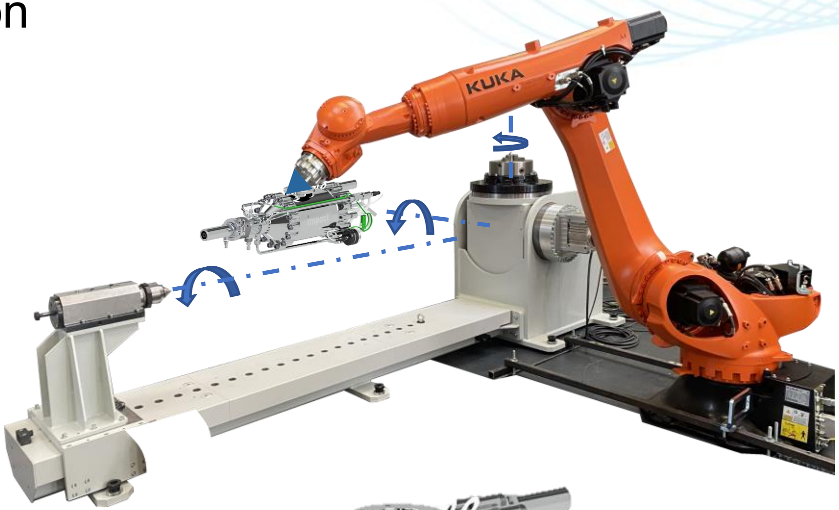


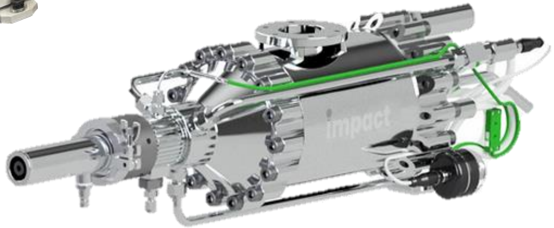
- Starting material: Magnetic powder + AL Binder
- Large geometries due to high application rate
- Materials with high density to be produced at low temperatures
  - Ideal for magnets

Source: https://doi.org/10.1007/s11666-007-9145-1 rapid + tct

Cold Spray: Equipment

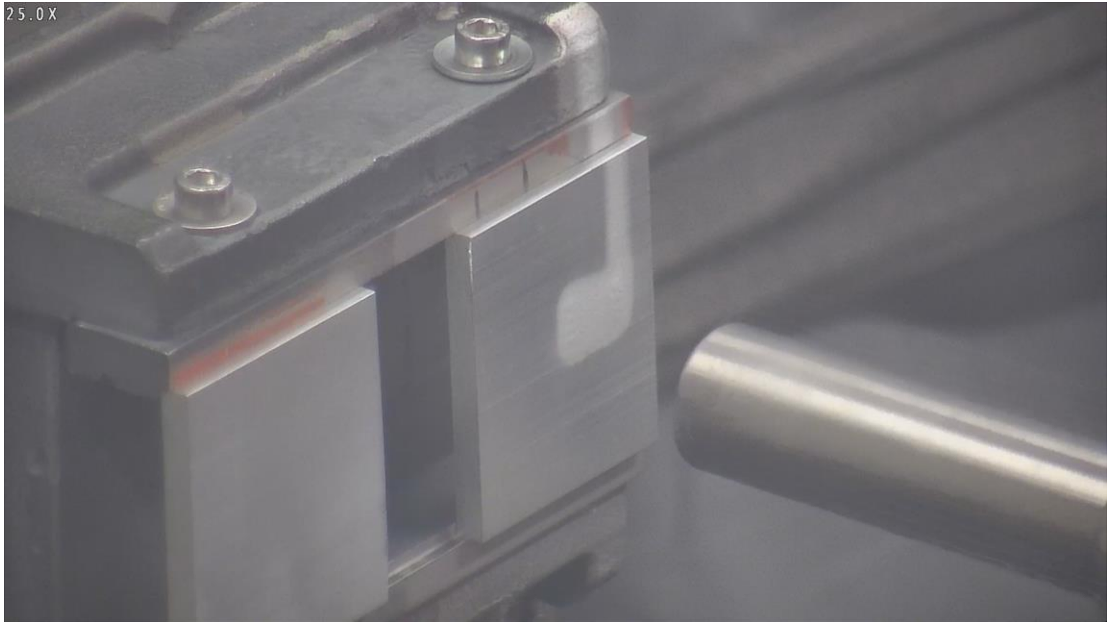
- Advanced hardware of the latest generation
- Industry robot (KUKA)
  - Nine axes
  - Reach: 2,000 mm
- Universal rotary table
  - Max. Diameter: 2000 mm
  - Max. Weight: 250 kg
  - Speed: 100 - 3,000 1/min.
  - Gas temperatur: 100°C - 1,100°C
  - Continuous tilting: 0° - 90 °

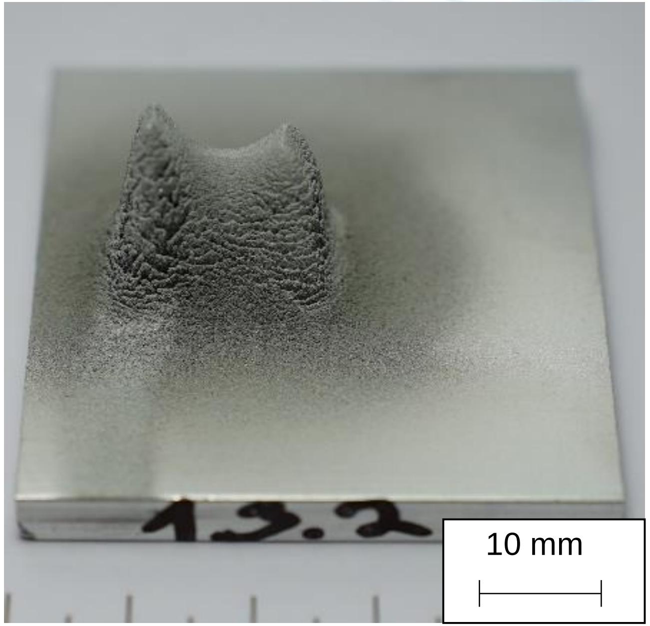




Source: Impact Innovations GmBH ©

Cold Spray

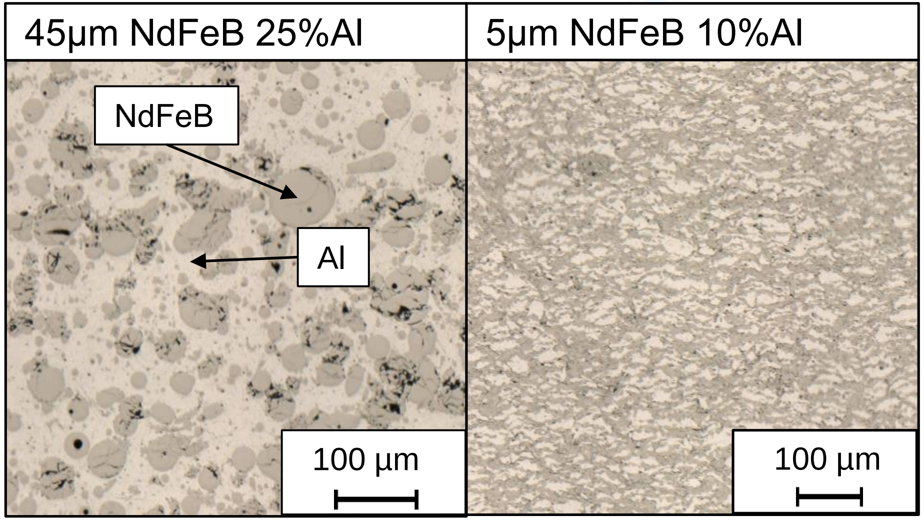




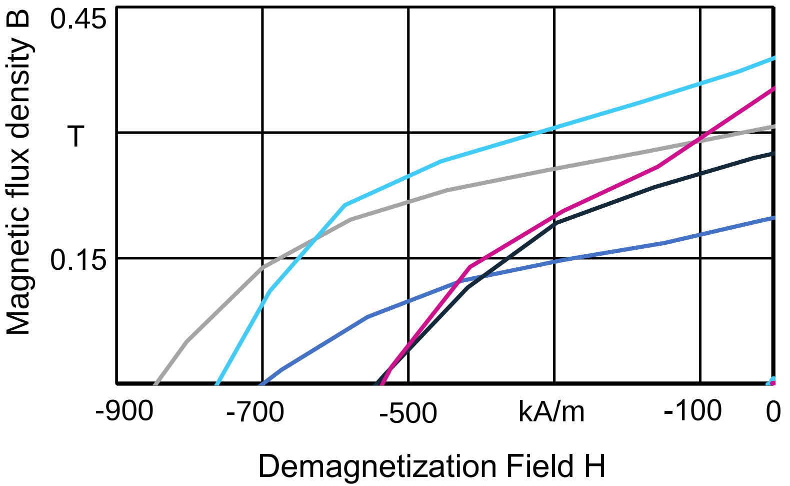
Magnetic materials

Material:
- Magnetic powder: NdFeB
  - Verry brittle
    –> use of ductile Binder material
- Binder: Aluminum

- 100% NdFeB not Possible at this point
  - Optimizing depositioning rate with optimal mixture and particle size



Results



- 1.1.3 ($d_{p,Nd2Fe14B}$ = 25 µm; $w_{Nd2Fe14B}$ = 75 %)
- 1.2.3 ($d_{p,Nd2Fe14B}$ = 5 µm; $w_{Nd2Fe14B}$ = 75 %)
- 1.3.3 ($d_{p,Nd2Fe14B}$ = 45 µm; $w_{Nd2Fe14B}$ = 75 %)
- 1.4.3 ($d_{p,Nd2Fe14B}$ = 25 µm; $w_{Nd2Fe14B}$ = 90 %)
- 1.5.3 ($d_{p,Nd2Fe14B}$ = 5 µm; $w_{Nd2Fe14B}$ = 90 %)

Specimen	Br (mT)	To reference	H_c (kA/m)	To reference
1.1.3	307	37.00%	854	90.80%
1.3.3	273	36.90%	544	81.20%
1.4.3	414	49.90%	741	78.30%

Process parameters:

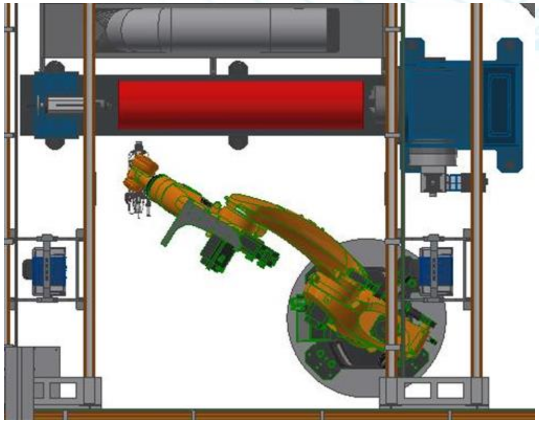
p_{gas}	=	50 bar
θ_{gas}	=	550 °C
a_d	=	30 mm
v_{gun}	=	500 mm/s
Process gas	=	Nitrogen
Binder	=	Aluminum

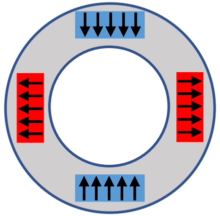
NdFeB – Magnetpowder:

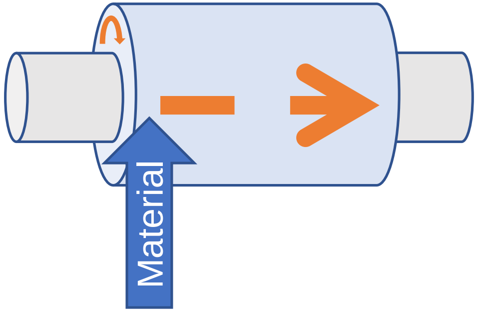
MQPF-14-12	(5 µm)
MQPF-14-12	(25 µm)
MQP-S-11-9	(45 µm)

Outlook

- Optimize magnetic properties
- Manufacturing of rotor magnet assemblies directly on shaft
- Better air gap tolerances due to elimination of the fixing sleeve
- Demonstrate cost-efficient production of large-scale motor/generator units
- Buried magnets







Acknowledgement

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THANK YOU!

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