Scaling up amorphous metals for EV parts using AM

eFlow Hub Webinar March 17, 2021:
The role of Additive Manufacturing (3D printing) in e-mobility and electrification

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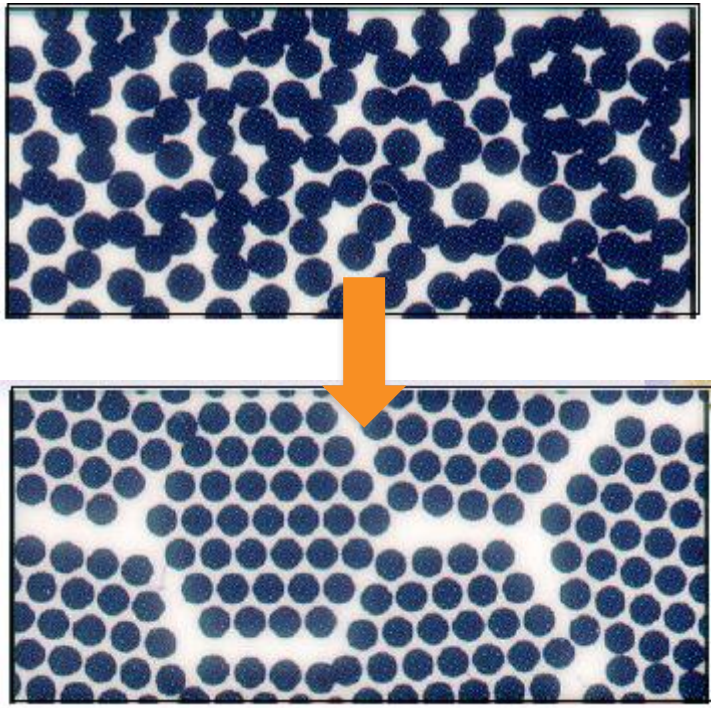
Outline

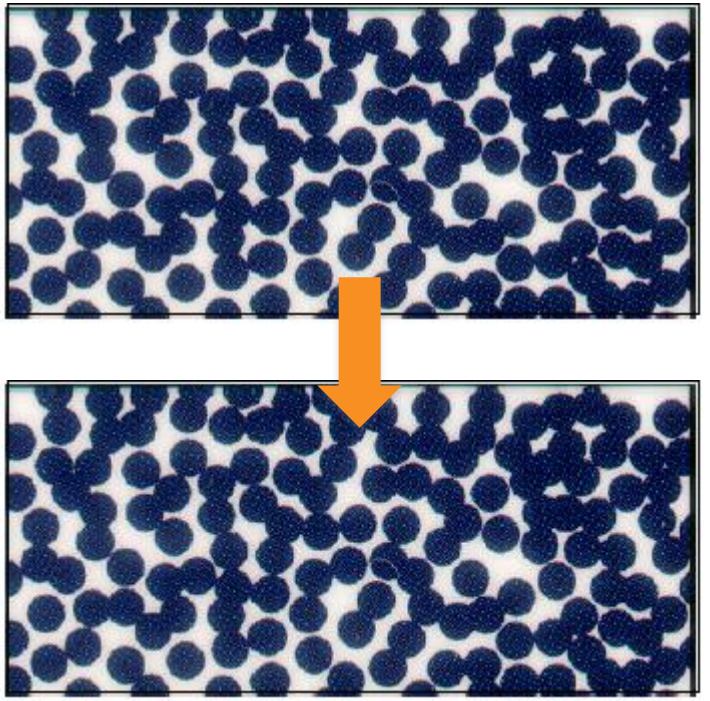
The presentation aims to answer these questions:

- **What?**
  - What happens if an alloy is solidified extremely quickly?
  - What is “amorphous metal”?
- **Why Amorphous?**
  - Why manufacturing soft magnetic amorphous metal components utilizing AM?
  - What benefits for EV parts and other technical applications?
- **Why Exmet’s method?**
  - The manufacturing challenge that Exmet solves by using AM
  - Exmet AB and our offer to industry

What happens if an alloy is solidified extremely quickly?

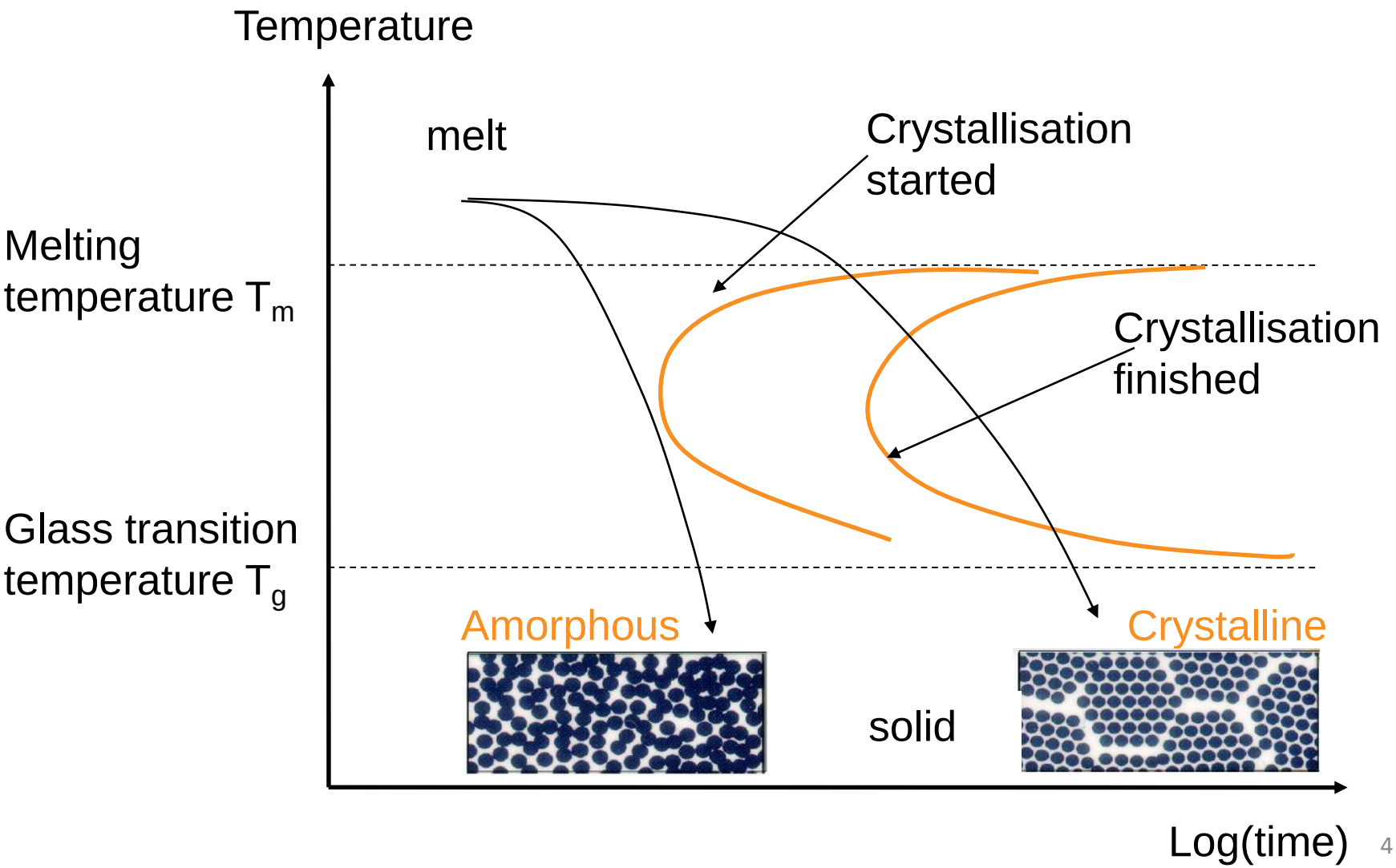


Crystalline material
- Ordered (long range order)
- Grain boundaries, polycrystalline microstructure



Amorphous material
- Disordered (no long range order)
- No grain boundaries
- No dislocations
- “A frozen liquid”

What solidification rate is needed?



What properties for such a quickly solidified alloy?

- **Ferromagnetic properties**
  - Low hysteresis/coercivity (10^0-10^1 A/m)
  - High permeability (10^3-10^4)
  - Moderate saturation (<1.5 T)
  - Good high frequency behaviour
  - High resistivity (10^2 μΩcm)
  - High mechanical strength (10^9 Pa)

- **Mechanical**
  - High strength
  - High elasticity (2%!)
  - Low loss/dissipation
  - High hardness/scratch-free surface
  - High wear-strength

- **Chemical (alloy base-dependent)**
  - High corrosion resistance/stainless
  - Excellent biocompatibility

- **Conductivity**
  - Low electric conductivity
  - Low thermal conductivity

- **Optical/Design**
  - High reflectivity

What if amorphous metal components were used in…

- Mechanical structures?

  → Improved properties → less material → lighter parts
- Electrical motors?

  → Increased efficiency due to great soft magnetic properties

Exmet AB offers material & process; our customers are specialists on their applications.

Manufacturing of Amorphous metals

- Known since 1960s, but sample dimensions have been limited due to difficulties to achieve efficient cooling throughout larger dimensions.
- Largest cross sections produced with conventional methods:
  Zr-alloys ≈ 30 mm, Fe-based ≈ 15 mm; many alloys only µm
- Interesting physical properties that could be useful in applications – if only larger dimensions could be achieved
- But – how to achieve high cooling rates for large dimensions?
- How about building just a thin layer at the time, followed by another thin layer….? Then complex components of any size could be manufactured!

Thickness	Method	Product
µm	Sputtering, Melt spinning	Thin films, Ribbons
mm	Thermal spray	Surface coatings
cm	Injection moulding in superplastic state	Bulk Metal Glasses
dm	Additive Manufacturing	Any shape, any size

In laser- and EBM-based metal AM-processes, the solidification rates are inherently extremely quick.

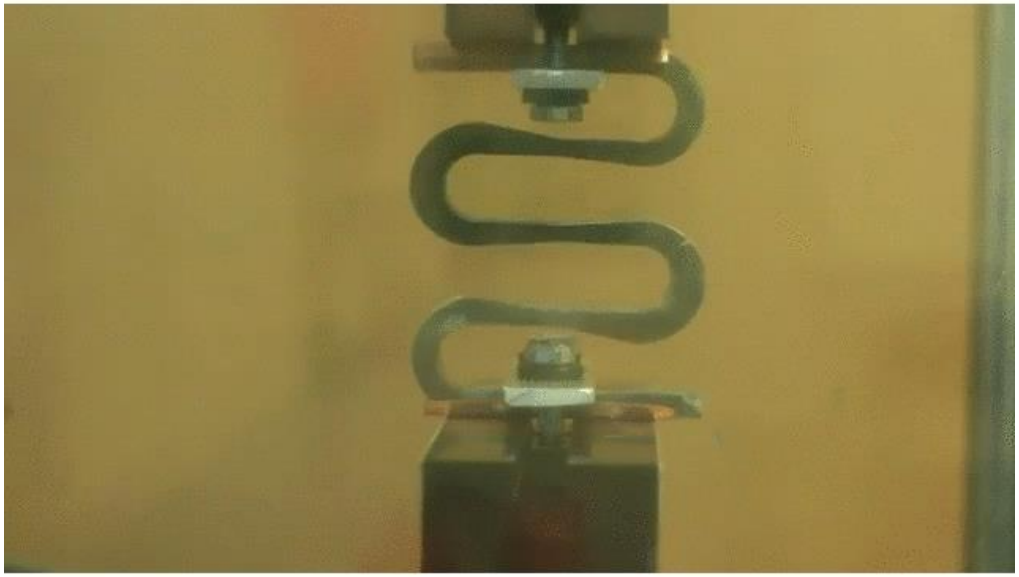
It appears to be a perfect match to use alloys that actually are intended for fast cooling
-- Amorphous alloys

(also known as Bulk Metallic Glasses, or glassy metals)

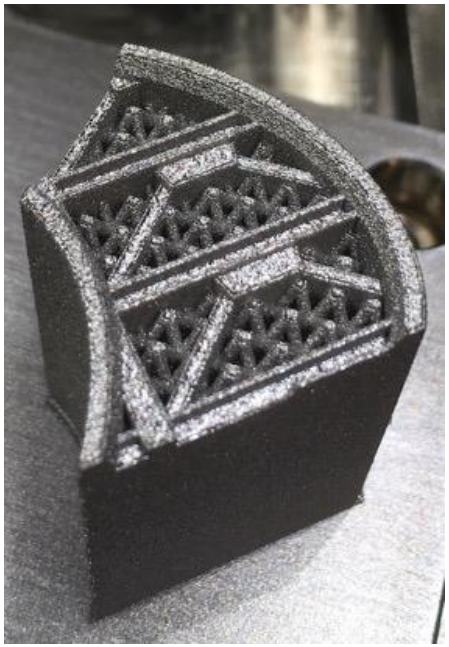
www.ge.com/additive/who-we-are/about-arcam and www.eos.info

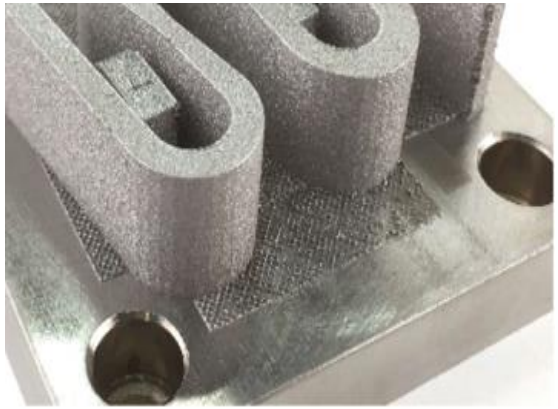
Exmet's First generation – Zr based

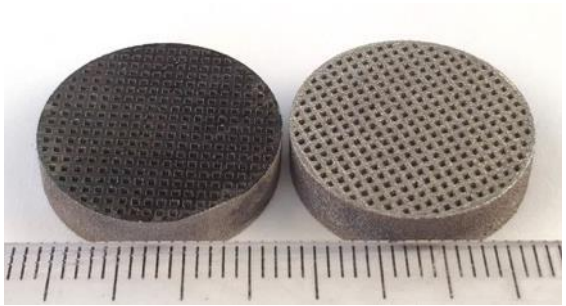
(available under trademark AMZ4 and/or Zr01 from licensee Heraeus)



Exmet's Second generation – Fe based

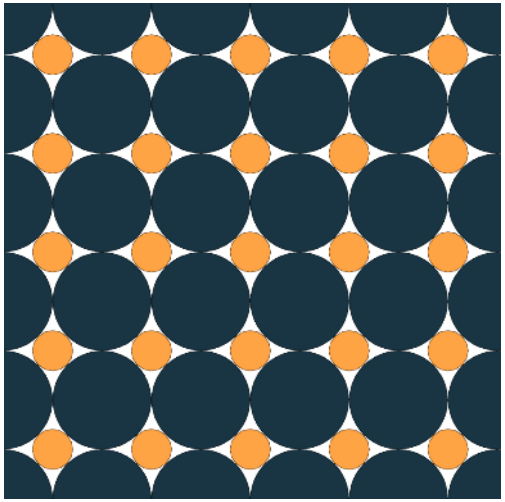






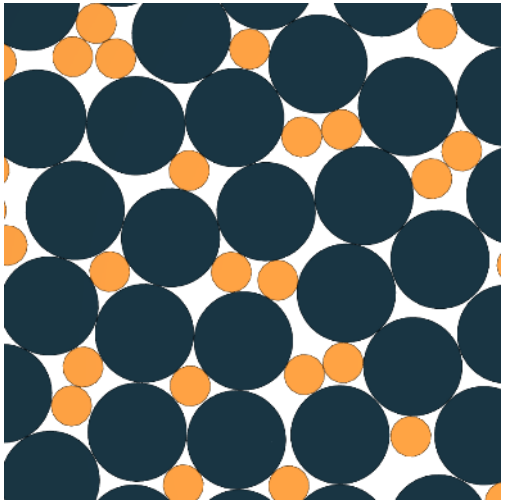
Density

Crystalline – higher densities



Dark blue: 25
Orange: 25

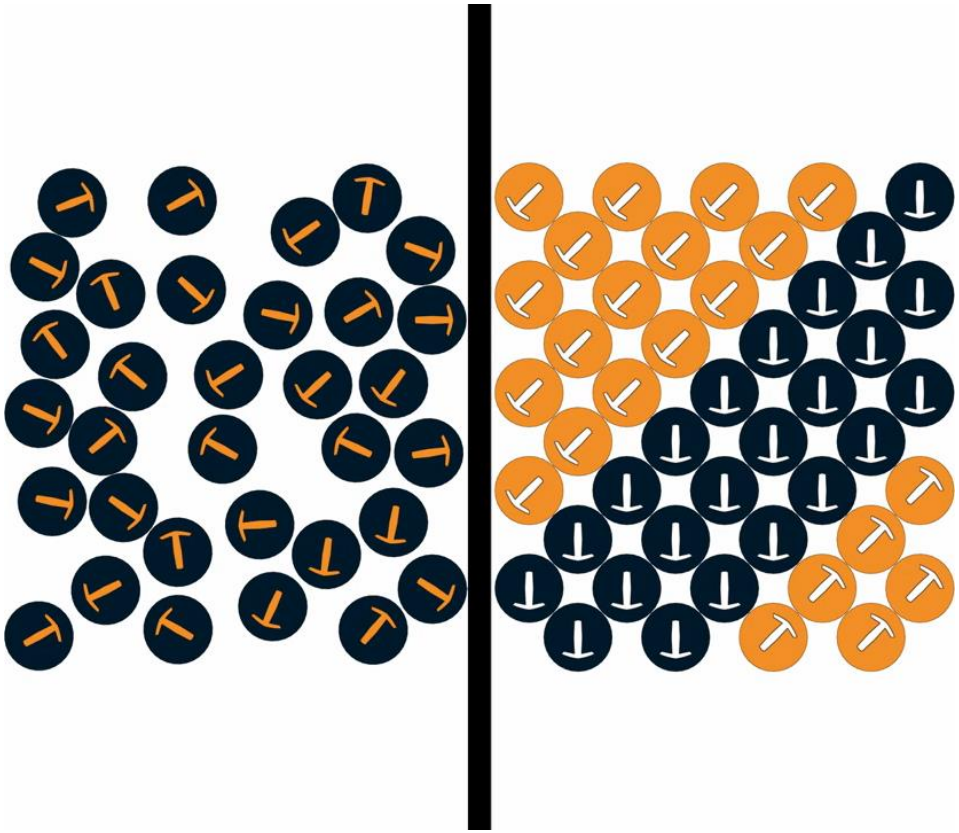
Amorphous – lower densities



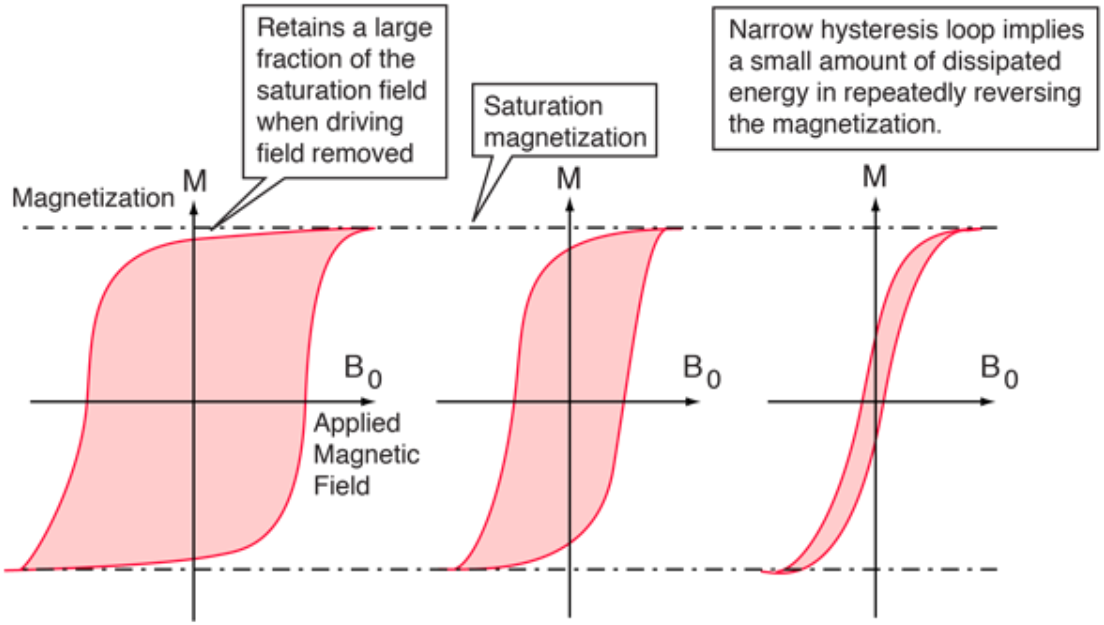
Dark blue: 20
Orange: 23

Magnetic permeability

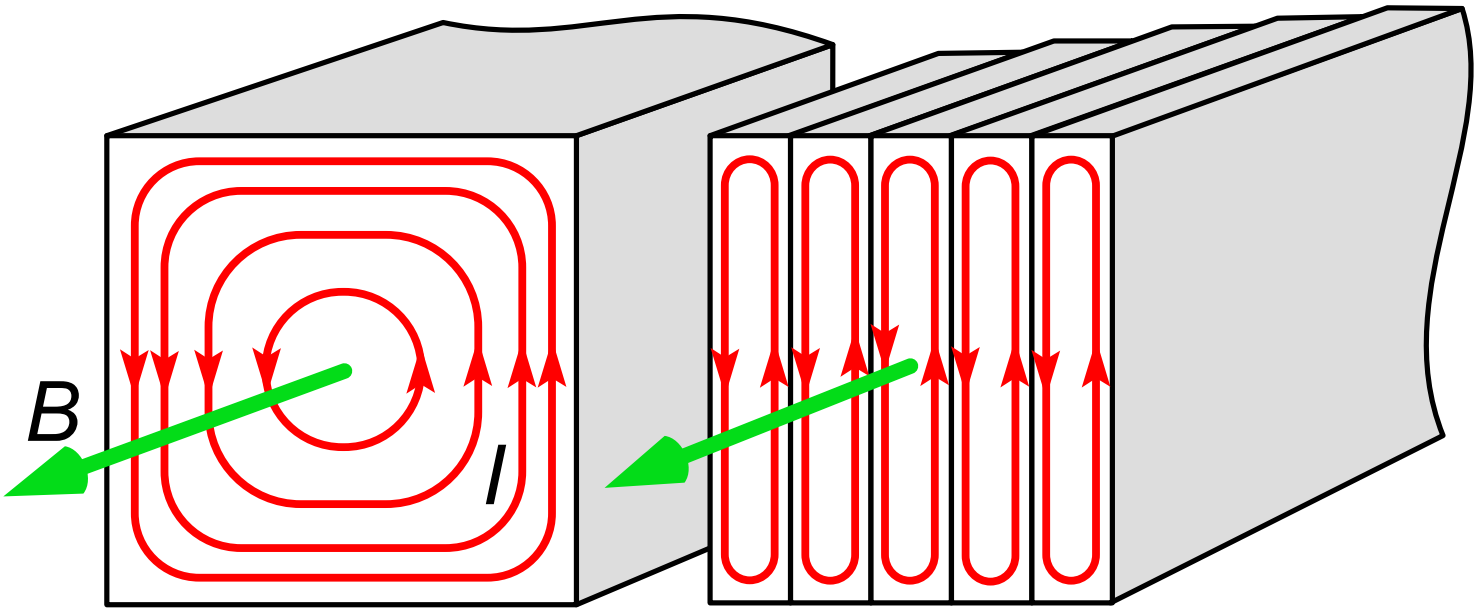
Animation



Coercivity


Retains a large fraction of the saturation field when driving field removed
Saturation magnetization
Narrow hysteresis loop implies a small amount of dissipated energy in repeatedly reversing the magnetization.
Magnetization
M
B_0
Applied Magnetic Field
Desirable for permanent magnets and magnetic recording and memory devices.
The area of the hysteresis loop is related to the amount of energy dissipation upon reversal of the field.
Desirable for transformer and motor cores to minimize the energy dissipation with the alternating fields associated with AC electrical applications.

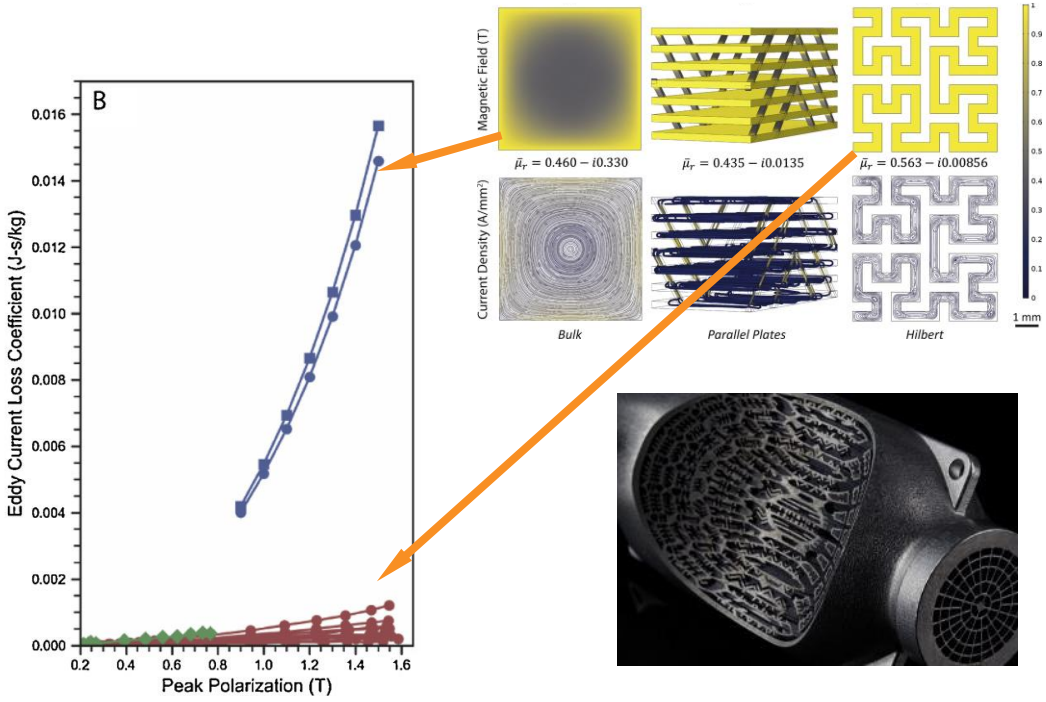
Resistivity: Bulk vs laminated



AM-manufactured soft magnetic amorphous alloys

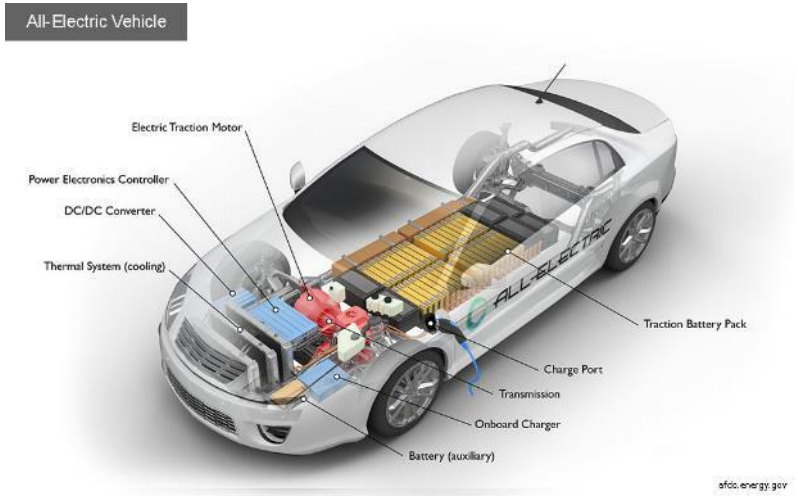
- Material properties
  - Low hysteresis/coercivity (10^0-10^1 A/m)
  - High permeability (10^3-10^4)
  - Moderate saturation (<1.5 T)
  - Good high frequency behaviour
  - High resistivity (10^2 μΩcm)
  - High mechanical strength (10^9 Pa)

- Design opportunities with AM including solutions to eddy current losses in bulk



Plotkowski, A.; Pries, J.; List, F.; Nandwana, P.; Stump, B.; Carver, K. & Dehoff, R. R. (2019), 'Influence of scan pattern and geometry on the microstructure and soft-magnetic performance of additively manufactured Fe-Si', *Additive Manufacturing* ***29, 100781.***

Electric vehicles – Identifying printable soft magnetic components



https://afdc.energy.gov/vehicles/how-do-all-electric-cars-work

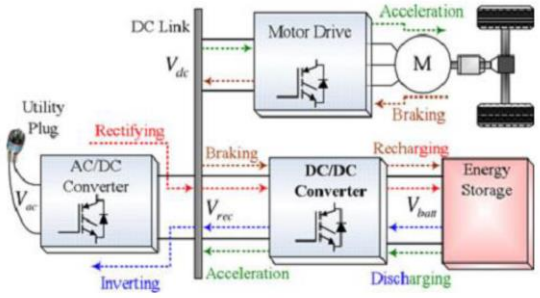
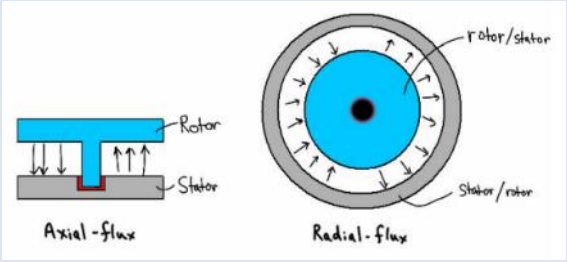
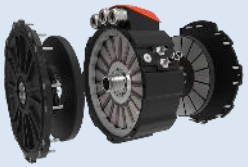


Fig. 3 Power electronics interface in EV.

Lulhe, A. M., & Date, T. N. (2015, December). A technology review paper for drives used in electrical vehicle (EV) & hybrid electrical vehicles (HEV). In 2015 International Conference on Control, Instrumentation, Communication and Computational Technologies (ICCICCT) (pp. 632-636). IEEE.

Motors



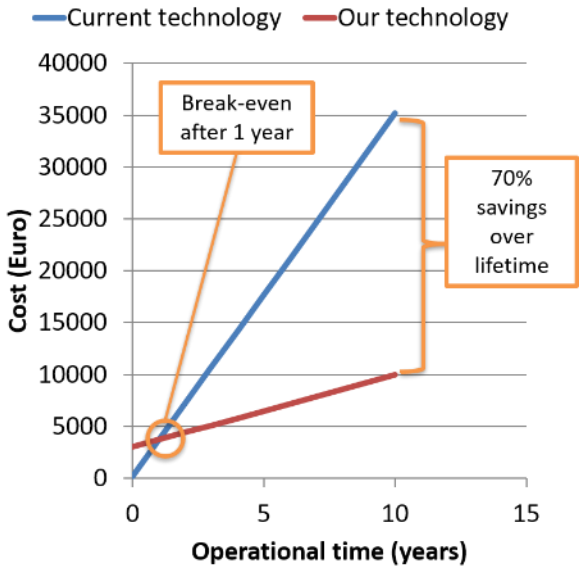


Converters

Value for customers and end-users?

Life cycle cost example for (20 kW) electric motor part

- Current technology:
  - Material: Few Euro
  - Manufacturing: Few Euro
  - In-service losses: 10 Euro/day
- Our technology:
  - Material: Lots of Euro
  - Manufacturing: Many Euro
  - In-service losses: 2 Euro/day



Industrialisation of metal AM will lower costs for material and equipment in coming years, thereby lowering the entry bar

For an EV, lower losses and lower vehicle weight translates to longer range and/or higher capacity, et c

ExMet AM²™

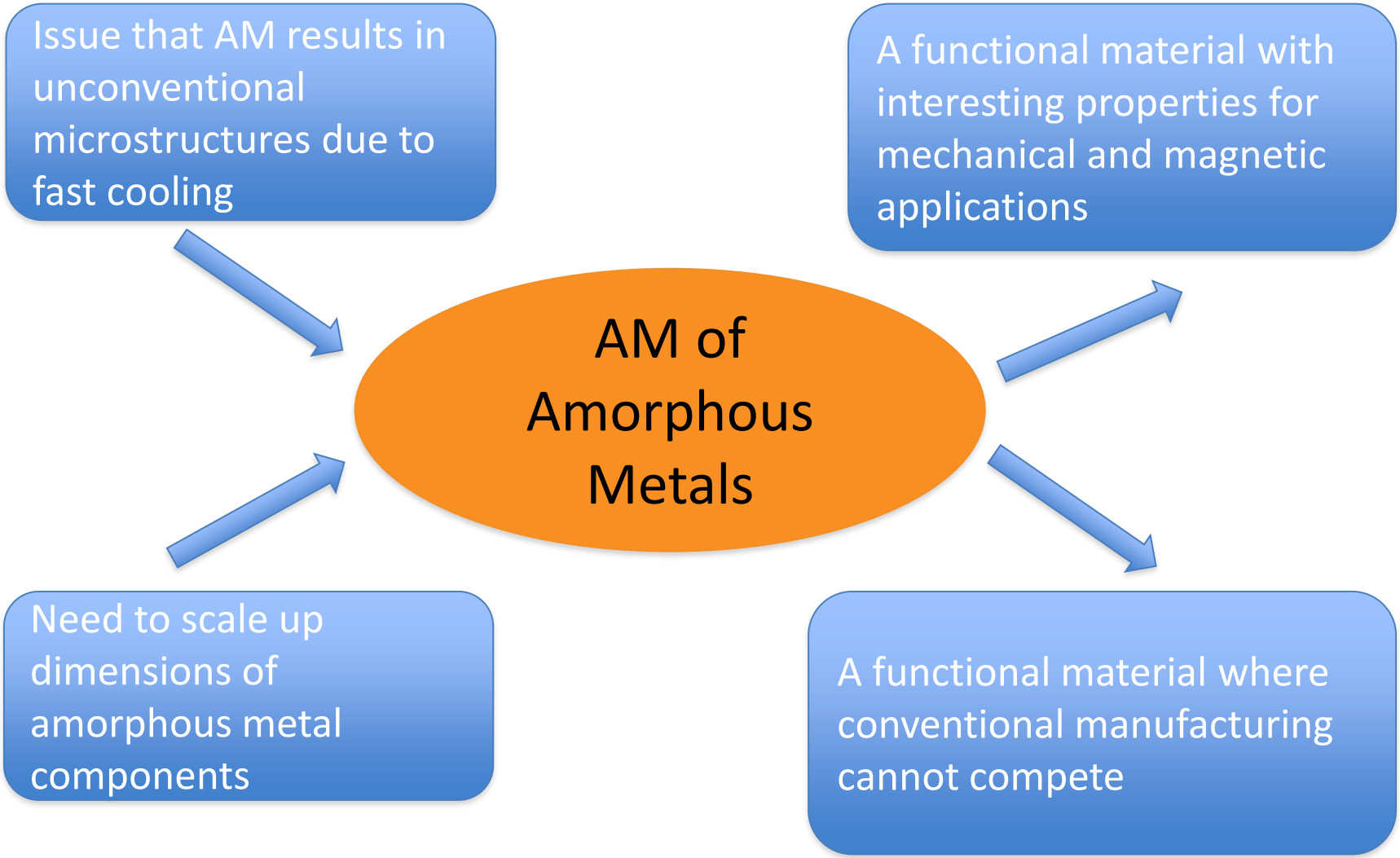
Exmet AB in brief:

- Exmet AB – an SME located in Stockholm, Sweden
- Inventor of proprietary technology
  - Amorphous metals through Additive Manufacturing
  - "Any shape, size and thickness"
- Key investors: AM Venture (EOS) and Volvo Cars
- Develops and supplies processes, powder and alloys

Our products and solutions:

- ExMet AM^2: Proprietary process technology
  - Enables the design and manufacturing of amorphous metal components using AM
- Metal Powder products for AM. Optimized alloys/powder for target applications
- Application support/development and prototyping.

In Conclusion



Thank you!

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