Graphmatech

Enabling the Green Transition with Graphene

Dr. Cecilia Århammar, R&D Manager, Business Development

WISE Networking Day

2025-01-22

About Graphmatech

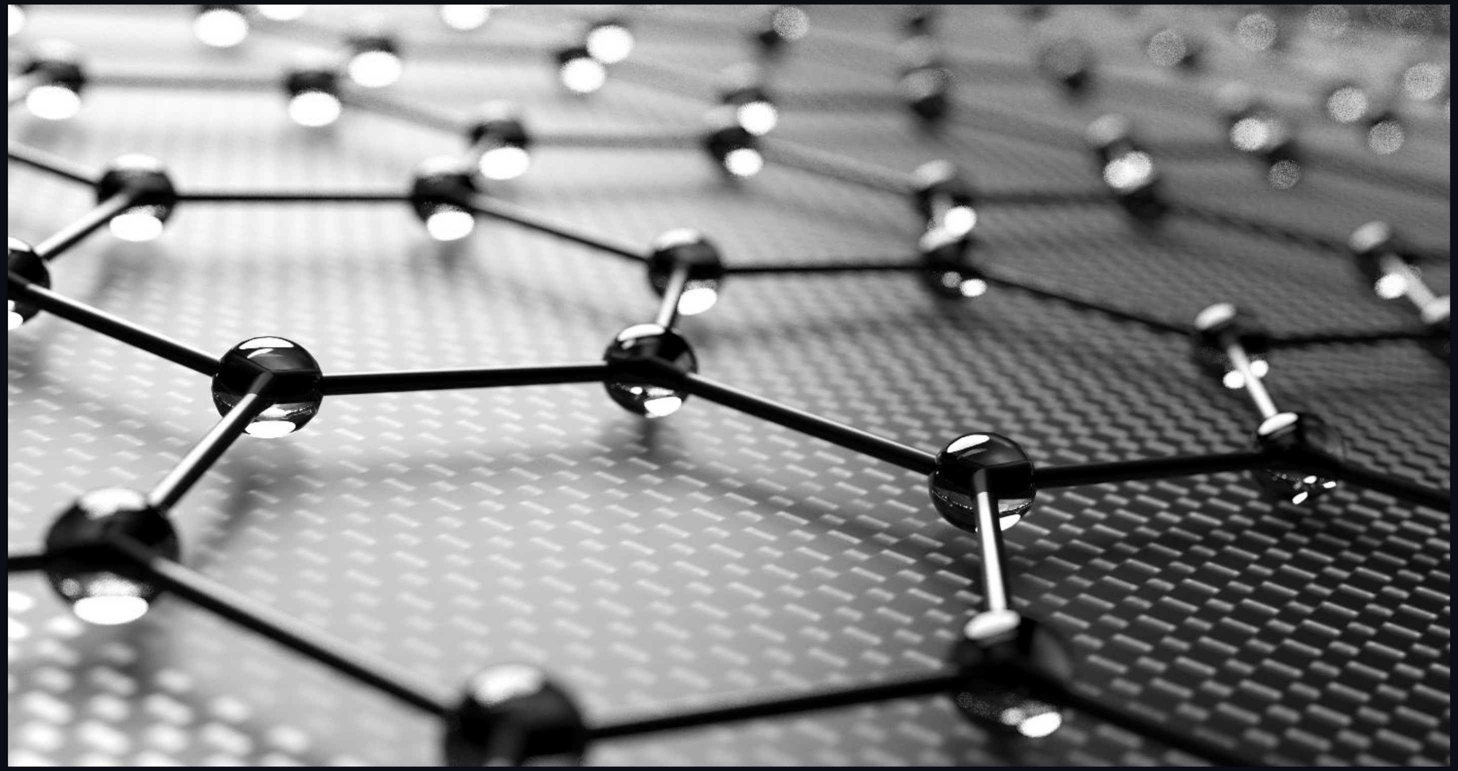
- Founded 2017 by Dr. Mamoun Taher
- Spin-off Uppsala University
- 15 Person Team
- Award-winning
- R&D and Production incl. 1350 sqm
- Production capacity polymer pellets 2 ton/year, upscaled in 2025 to 50 ton/year
- Production capacity metal powder up to 100 kg/batch
- Access to Ångström laboratory clean room and other equipment at Ångström laboratory
- Investors: ABB, InnoEnergy, Molindo Energy, Almi Green, Walerud Ventures

Graphene is a super material with unique properties, suitable for a range of industrial uses

Graphene, discovered in 2004, is a material extracted from graphite.

It is made up of pure carbon atoms bonded together in a hexagonal sheet-like structure.

Each sheet is one atom thick



Graphene's unique properties:

Strong	Graphene is the world's strongest material - 200x stronger than steel
Light-weight	1000x lighter than a piece of thermal paper 5x lighter than aluminium
High conductivity	Exhibits a conductivity of ~4000 $Wm^{-1}K^{-1}$ - 70% higher than copper
Abundant	Can be produced from various raw materials, including graphite, methane cracking, and waste recycling

Graphmatech in a value-adding, defensible and extremely scalable value chain position

Raw material suppliers
(polymers, metals, battery materials)

Graphene suppliers

- Low barrier to entry
- Commodity pricing
- High competition potential

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Engineering materials with graphene patented technology and manufacturing

- High value-adding step
- Customer reliance
- Highly defensible (patents)
- Possible value-added pricing model

Component manufacturers
(e.g. pipes, vessels, packaging, batteries, cables)

- High capex required
- Potentially competitive
- Supplier reliance

Systems Manufacturers
(e.g. gas utilities, automotive, defense, packaging)

Graphene properties in industrial applications could bring significant benefits…

Graphene properties …

- Strength
- Flexibility
- Conductivity
- Light weight
- Low friction
- Barrier for gas molecules

… make materials better

Polymers
- Conductive: ESD, EMI, Radar absorption
- Barrier: Prevent hydrogen from escaping from tanks and pipes.
- Extend product shelf life by preventing gas leaking into - or out of packaging
- Improved mechanical properties
- Flame retardant , UV protection

Better metals
- No need for lubrication between metal parts
- Stronger metals that conduct more heat and electricity

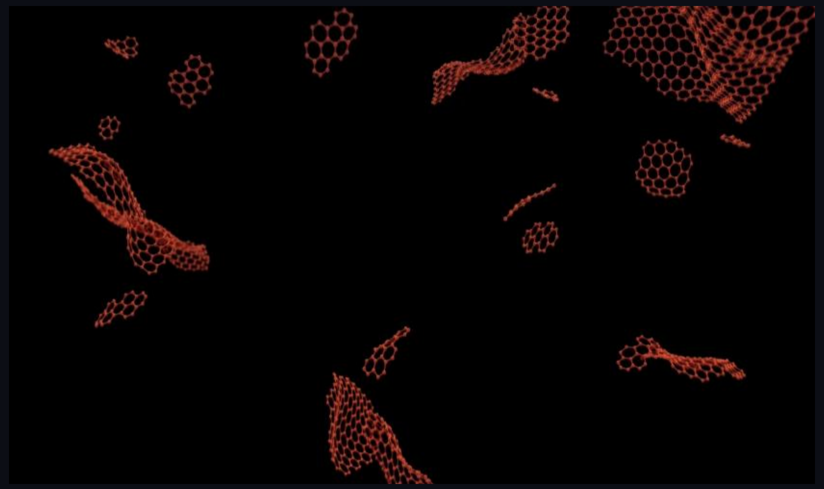
3D printing
- Copper: SLM printing of 99,95% dense components with a smooth finish, more conductive, stronger and harder components
- Polymers (FDM and SLS printing): ESD, EMI shielding, radar absorption with filaments or powder

Better batteries
- 80% increased lifetime in sodium ion batteries
- 20% increased energy density in Li-Ion cathodes

AROS GRAPHENE® AROS COAT ®

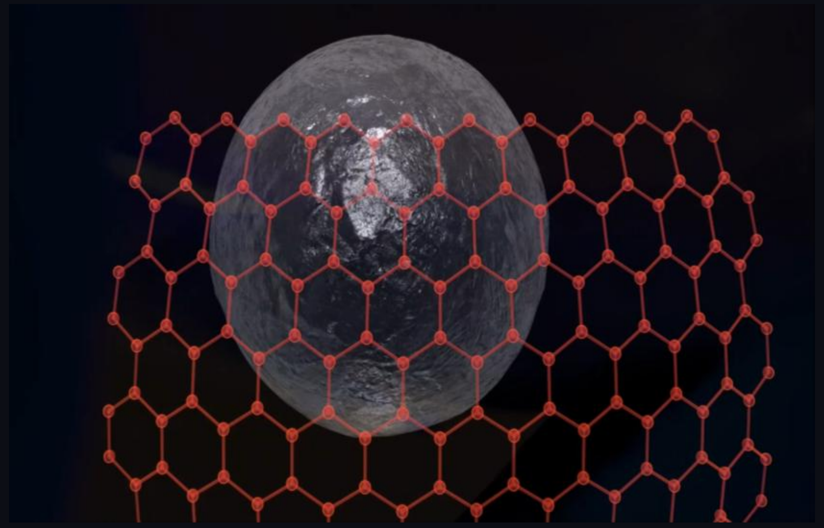
Our technology platform enables effective incorporation of graphene and performance

AROS GRAPHENE®



Retain graphene properties

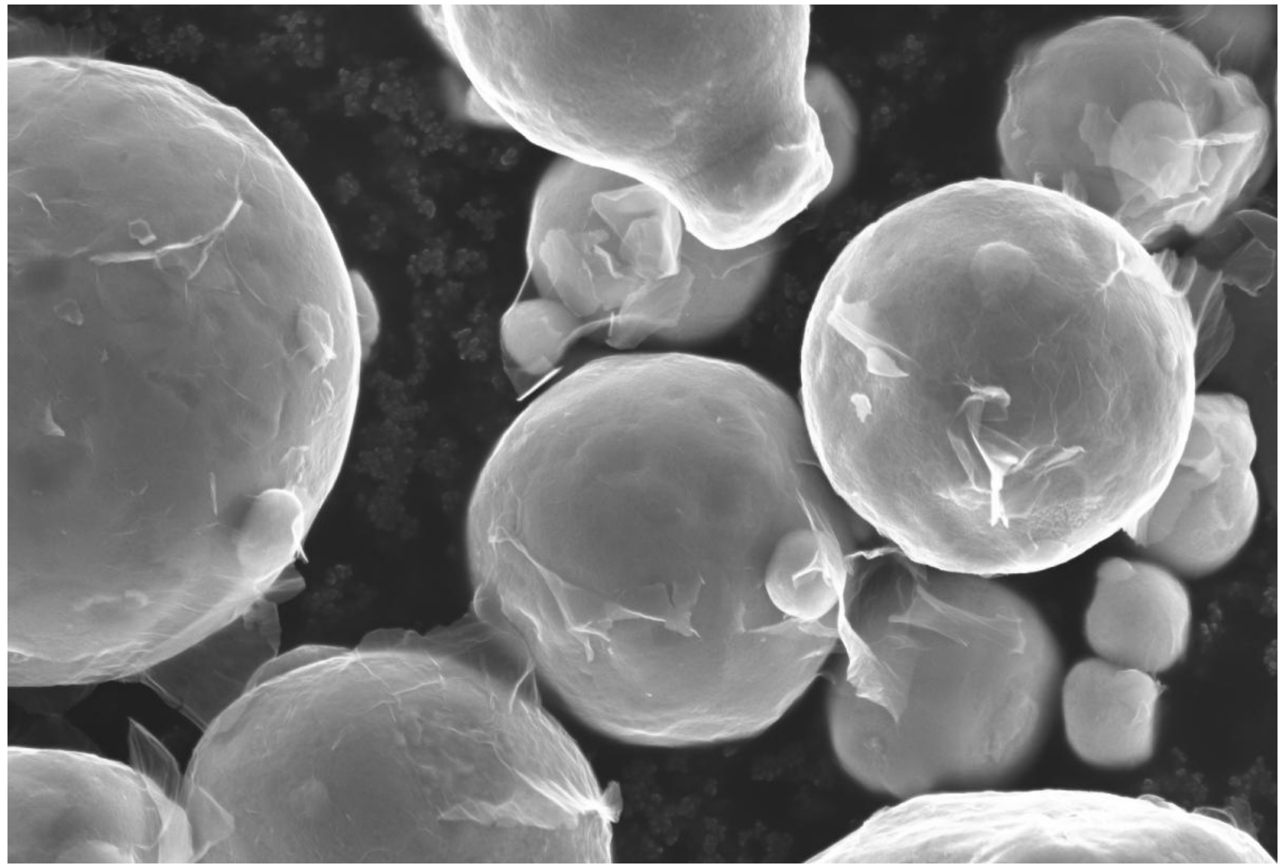
AROS COAT®

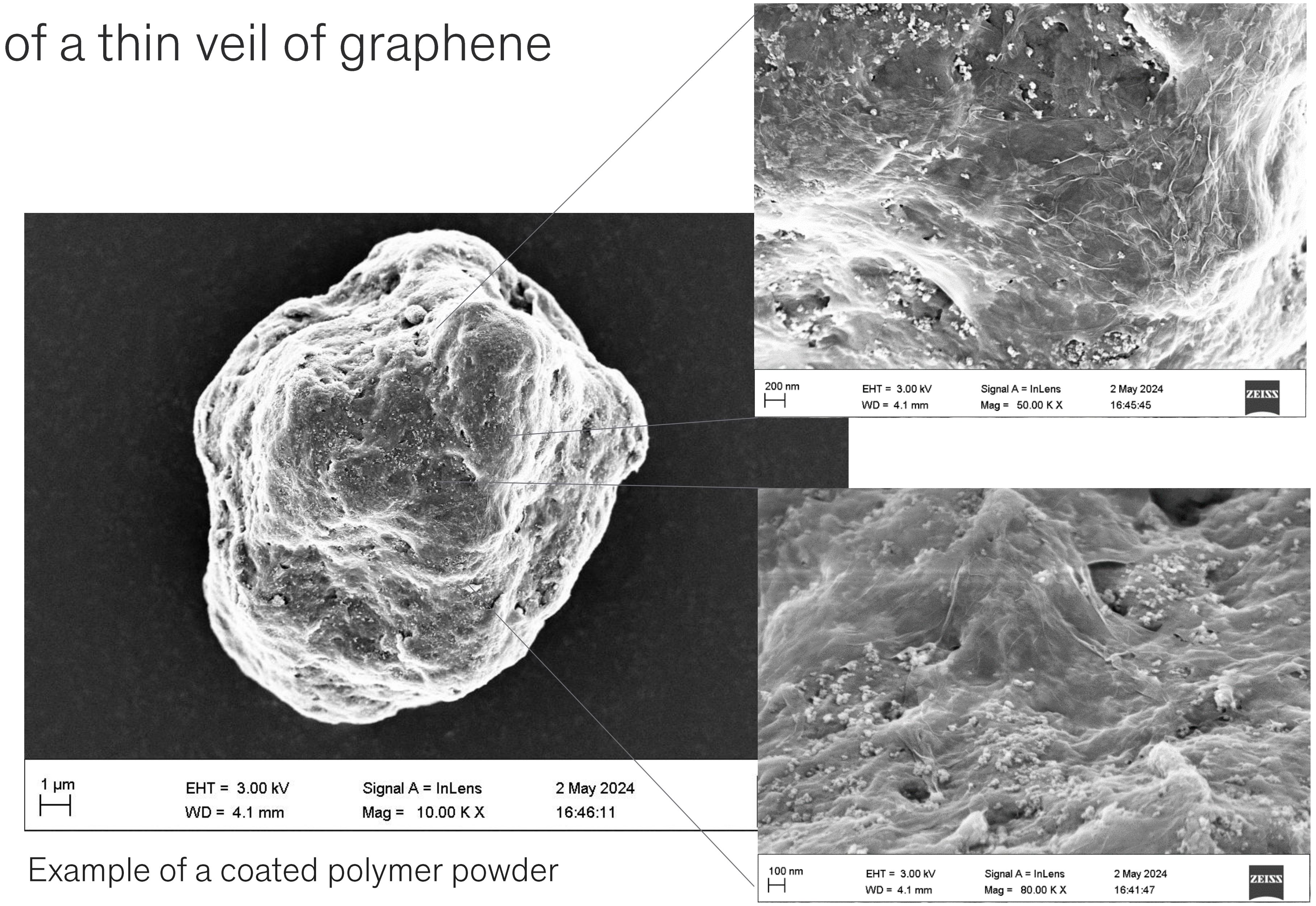


Graphene integration with other materials

Graphene integration with other materials

- Our patented technology enables the coating of a thin veil of graphene onto various powders

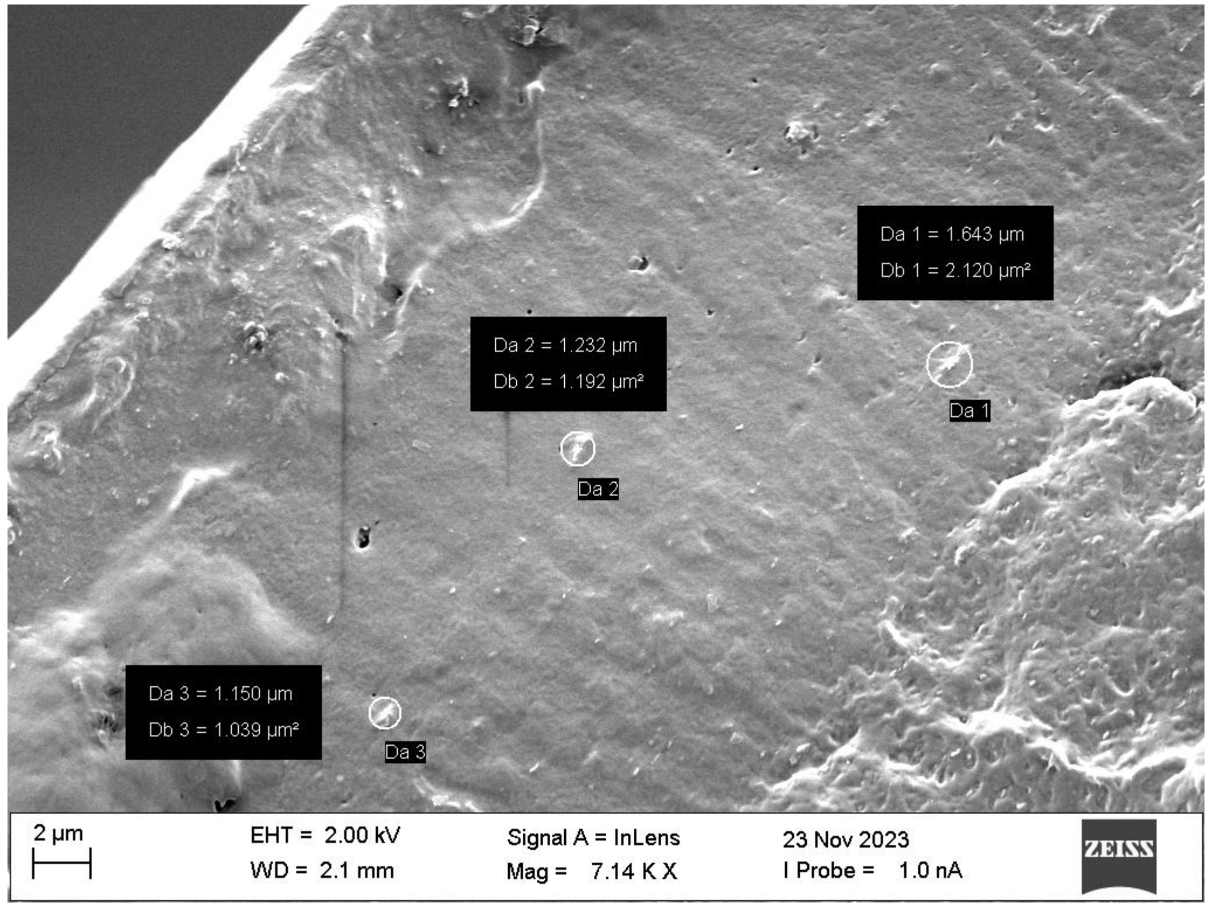

Example of a coated metal powder



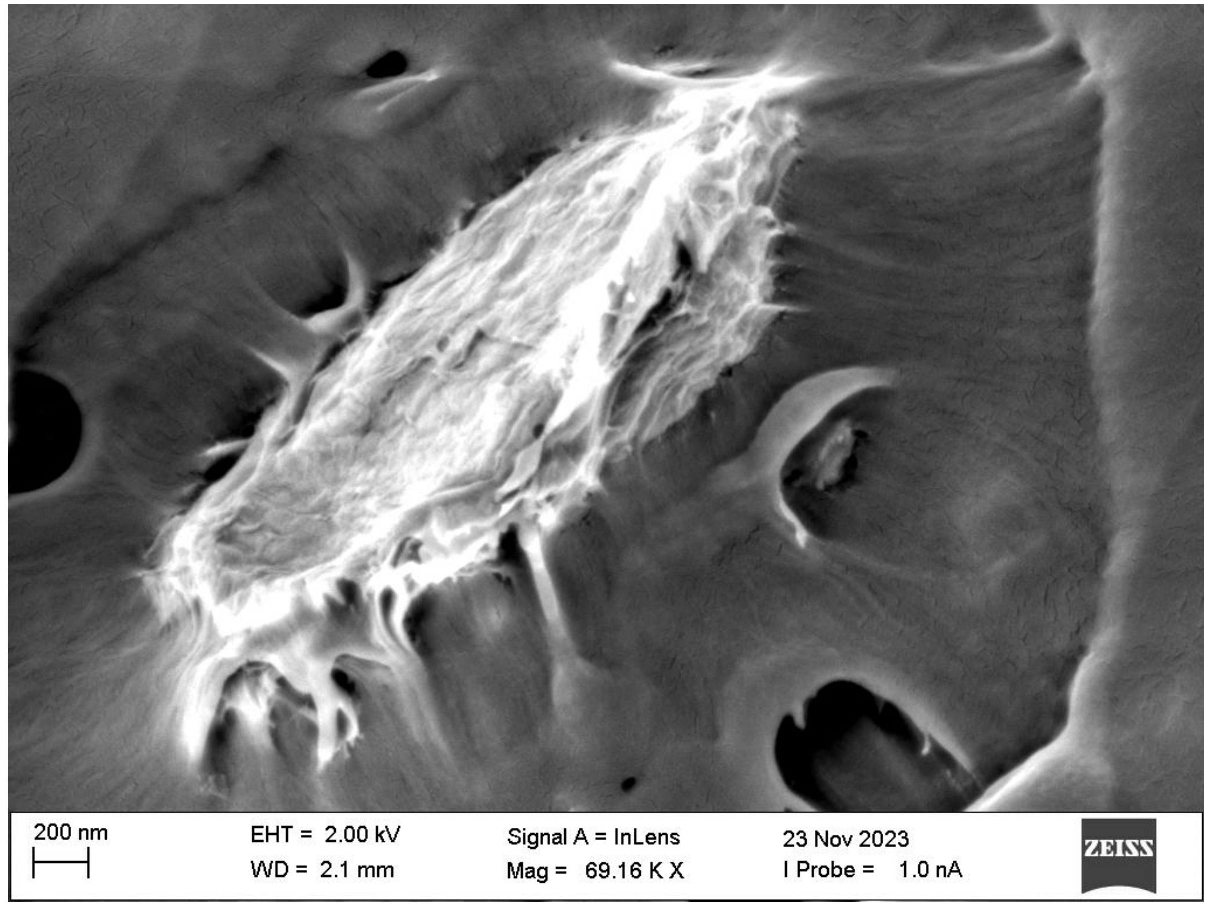
Example of a coated polymer powder

Graphene integration with other materials

- Integration of graphene into different polymers (PE, PA, PP etc.) via extrusion



Example of a masterbatch with PA11 and graphene



Zoom-in on a graphene particle in a masterbatch with PA11 and graphene

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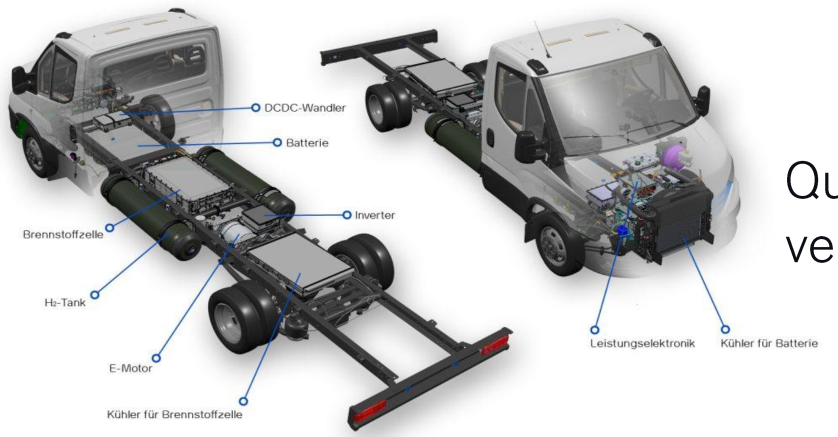
Towards high-performance graphene composites for hydrogen storage

WISE PhD Malte Åberg
Supervisor: Prof. Martin Sahlberg, Uppsala University, Paul Henry, ISIS
Company Supervisor: Cecilia Århammar, Graphmatech

The potential of Hydrogen

- According to the Economist, hydrogen technologies could eliminate a tenth of today's greenhouse gas emissions by 2050, which can be seen as a crucial and lucrative opportunity
- Over a dozen countries, including Britain, France, Germany, Japan and South Korea, have national hydrogen plans and there are over 350 big projects under way to tackle the technological challenges



Quantron FCEV vehicle

Alsthrom Cordia ILINT FCEV train

HexagonPurus mobile hydrogen distribution systems

Norway's hydrogen fuel cell ferries – photo The Norwegian Ship design company

The potential of Hydrogen

- There is a strong demand in the automotive market for cost-effective and efficient high-pressure hydrogen pressure vessels.
- The major challenge today is the integration of hydrogen storage systems that fulfil customers' autonomy range expectations and durability.
- Hydrogen is approximately 11 times more harmful to the environment than CO_2 over a 100-year period, and so any leaks from hydrogen storage and transport can significantly contribute to climate change*

*Sand, M., Skeie, R.B., Sandstad, M. *et al.* A multi-model assessment of the Global Warming Potential of hydrogen. *Commun Earth Environ* **4**, 203 (2023). https://doi.org/10.1038/s43247-023-00857-8

Key limitations hydrogen technology

- Hydrogen is normally stored and transported either in metal (type III) or polymer-based (type IV) pressure vessels or pipes

- With the growing hydrogen economy, solutions for storage and transport of hydrogen become increasingly important.

- There are some important limitations with hydrogen technology…

- **Hydrogen embrittlement (metals)**

- **Leakage of hydrogen gas (polymers and metals)**

- Materials which withstand hydrogen embrittlement and efficient limits hydrogen permeation are needed to enable technology

Hydrogen permeability of polymers and metals

Material	Permeability $[kg \cdot m^{-1} s^{-1} bar^{-1/2}] / [kg \cdot m^{-1} s^{-1} bar]$
Iron, iron alloys	$2.3\text{-}9.4 \cdot 10^{-14}$
Steel	$8.2 \cdot 10^{-14}$ -1.66 $\cdot 10^{-14}$
Polyethylene (HDPE)	$3{,}2 \cdot 10^{-14}$ – $7.7 \cdot 10^{-13}$
Polyamide	$1.3 \cdot 10^{-14}$ – $1.6 \cdot 10^{-14}$
Nickel	$2.1 \cdot 10^{-17}$ – $2 \cdot 10^{-15}$
Zink	$1.4 \cdot 10^{-18}$ - $2 \cdot 10^{-17}$
Aluminum	$3.2 \cdot 10^{-23}$ - $5 \cdot 10^{-21}$

Source: Dennis Krieg, Konzept und Kosten eines Pipelinesystems zur Versorgung des deutschen Straßenverkehrs mit Wasserstoff, Julich Forschungscentrum

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Polyethylene (HDPE)	$3,2 \cdot 10^{-14}$ – $7.7 \cdot 10^{-13}$
Polyamide	$1.3 \cdot 10^{-14}$ – $1.6 \cdot 10^{-14}$
Polyamide-11	$8.2 \cdot 10^{-14}$
Polyamide-11 - graphene	$4.0 \cdot 10^{-14}$ – $7.9 \cdot 10^{-14}$
Polyamide-6	$1.9 \cdot 10^{-14}$
Polyamide-6 - graphene	$7.7 \cdot 10^{-15}$ – $1.8 \cdot 10^{-14}$
Nickel	$2.1 \cdot 10^{-17}$ – $2 \cdot 10^{-15}$
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Source: Dennis Krieg, Konzept und Kosten eines Pipelinesystems zur Versorgung des deutschen Straßenverkehrs mit Wasserstoff, Julich Forschungscentrum
Data measured at external lab according to ASTM D1434-82 (Manometric, procedure M) at 20 Bar and 50 °C.

Hydrogen embrittlement

- "Hydrogen Embrittlement is one of the biggest obstacles for the deployment of hydrogen energy infrastructure, including the repurposing of natural gas pipelines for the transport of gaseous hydrogen"[1]
- Failure of energy infrastructure due to Hydrogen Embrittlement could lead to life-threatening accidents – just one major incident could cause a setback in the worldwide application of hydrogen for decarbonization

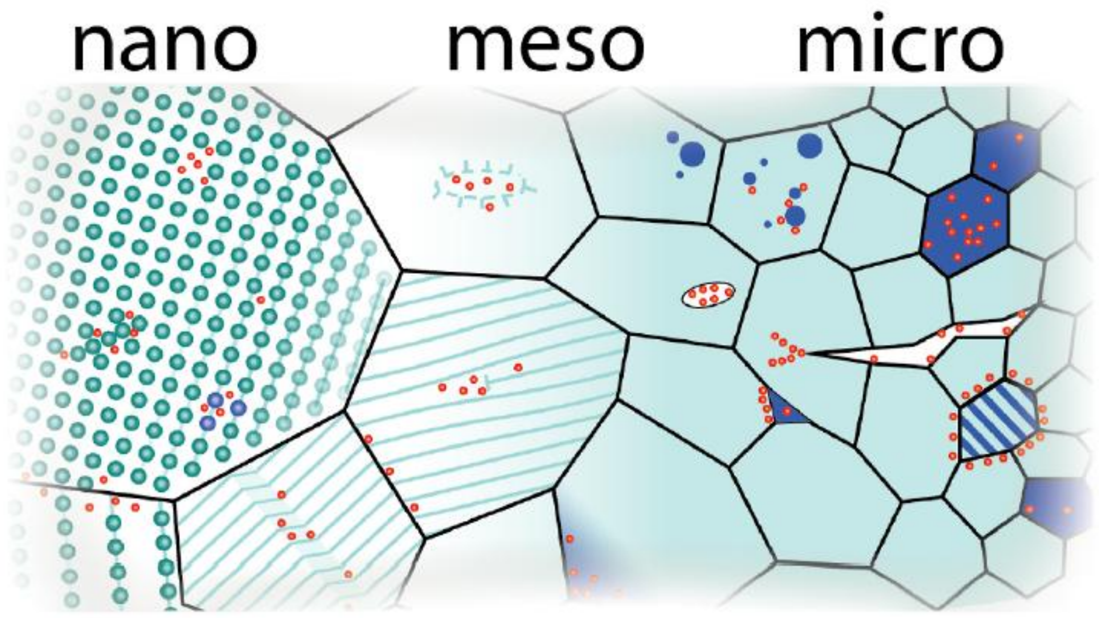


Illustration of various microstructural hydrogen traps in an alloy. Hydrogen can be trapped at interstitial lattice sites, grain boundaries, vacancies, alloying solutes, stacking faults, twins, dislocations and their cell walls,strain field, voids, second phases and their boundaries, and the free surfaces of microcracks.

1 Chen et al, Hydrogen trapping and embrittlement in metals – A review, International Journal of Hydrogen Energy, April 2024, In press.

Graphmatech

Understand key properties of polymer-graphene composites for hydrogen storage and transport

WISE PhD, Malte Åberg, Process Engineer

Overall objectives WISE PhD

- Understand key properties of polymer/graphene composites for hydrogen storage/transport

Metal-graphene solutions for hydrogen

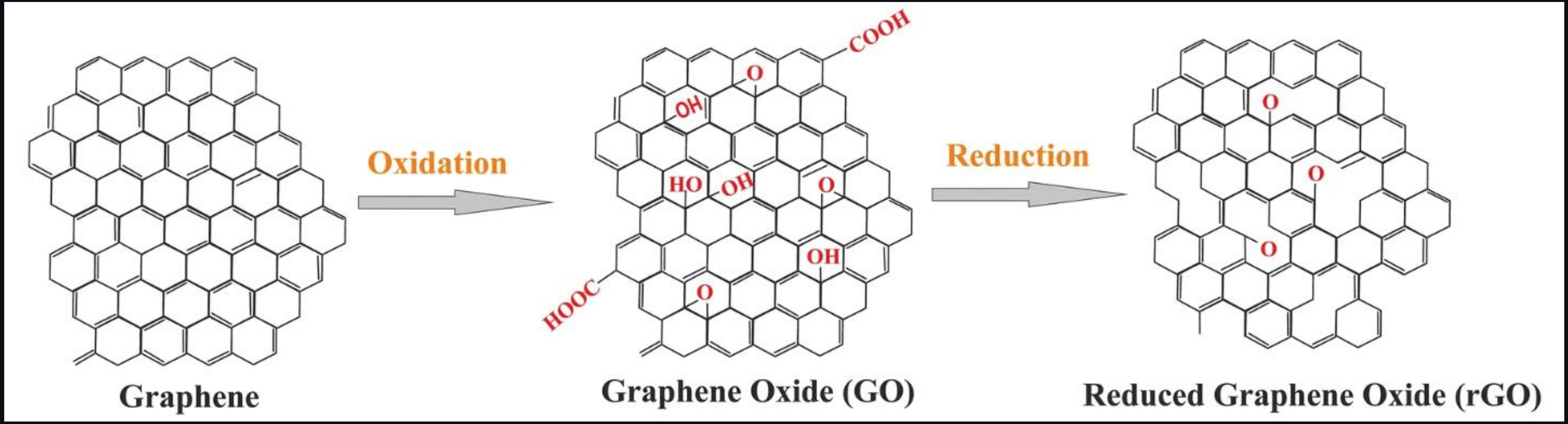
- Identify if metal-graphene powders can be used to reduce hydrogen embrittlement effects
  - Understand the mechanisms of hydrogen embrittlement
- Investigate different manufacturing techniques and how they influence graphene
- Other (direct and indirect) effects of graphene additio
  - Corrosion resistance
  - Mechanical properties

} Microstructure – grainsize, precipitates

Graphene oxide and reduced graphene oxide

The oxygen containing functional groups can be protonated or deprotonated which creates surface charges that can be used for:

- ➢ Separation of GO-sheets in solution
- ➢ Attaching the GO-sheets to surfaces with positive surface charge



Priyadarsini et al, J. Nanostructure Chem., 8, 123-137, 2018

→ Use electrostatic interactions to homogeneously distribute negatively charged GO-sheets on positively charged powders

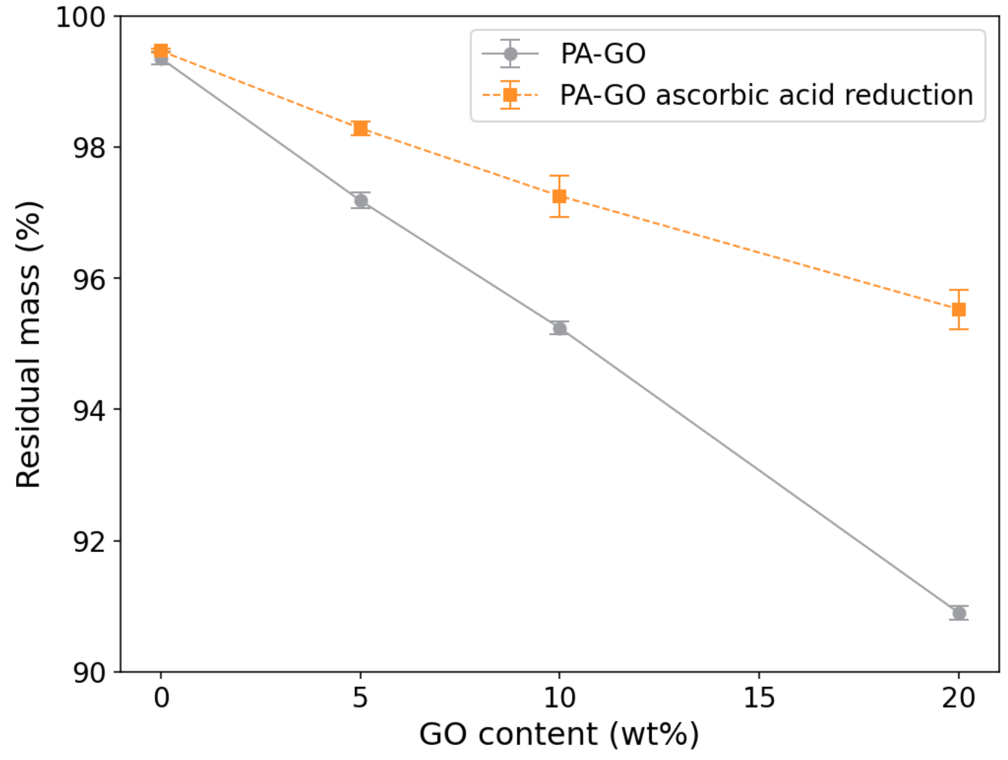
→ Reduction before or during consolidation

Thermal and chemical reduction of graphene oxide in polyamide composites

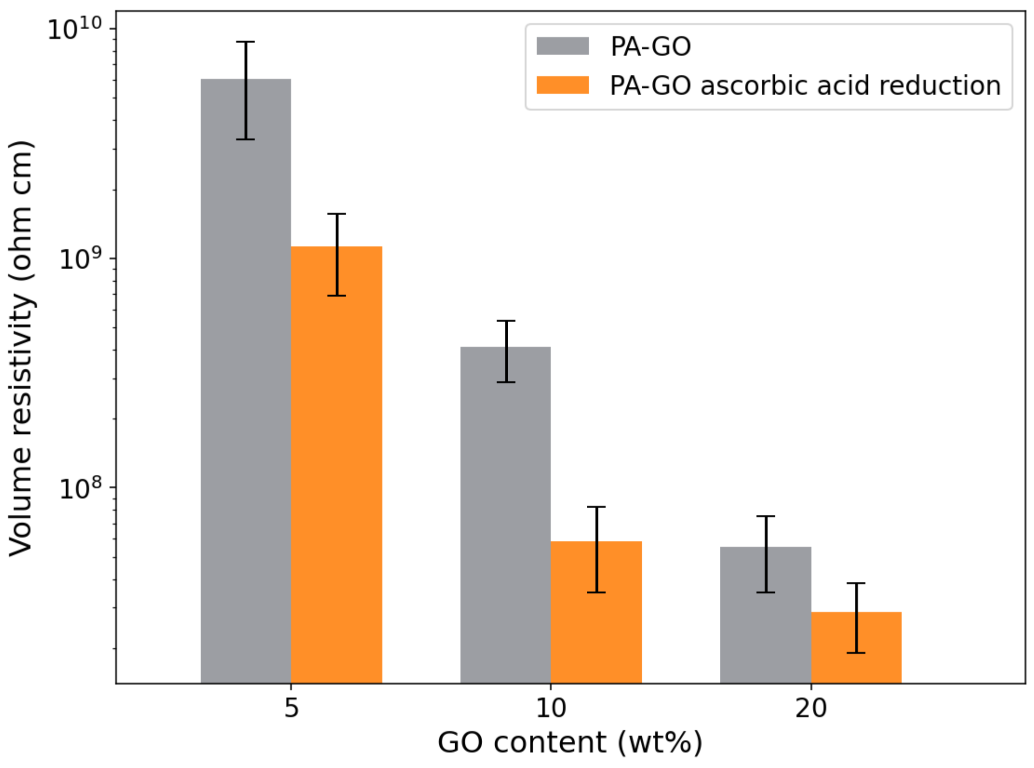
- Graphene Oxide (GO) is one of the raw materials used at Graphmatech
- GO has shown to have good barrier properties and can potentially be used for hydrogen barrier applications
- GO is easy to handle (paste/suspension form), relatively low cost and enables interaction to polymer and metal surfaces due to its functional groups.
- GO is known to thermally reduce at common polymer processing temperatures, resulting in gas evolution[1]
- Gas evolution during part manufacturing, e.g. 3D printing can reduce quality of finished parts

1 I. Sengupta, S. Chakraborty, M. Talukdar, S. K. Pal, and S. Chakraborty. (2018). Thermal reduction of graphene oxide: How temperature influences purity. J. Mater. Res., vol. 33, no. 23, pp. 4113–4122, 10.1557/jmr.2018.338

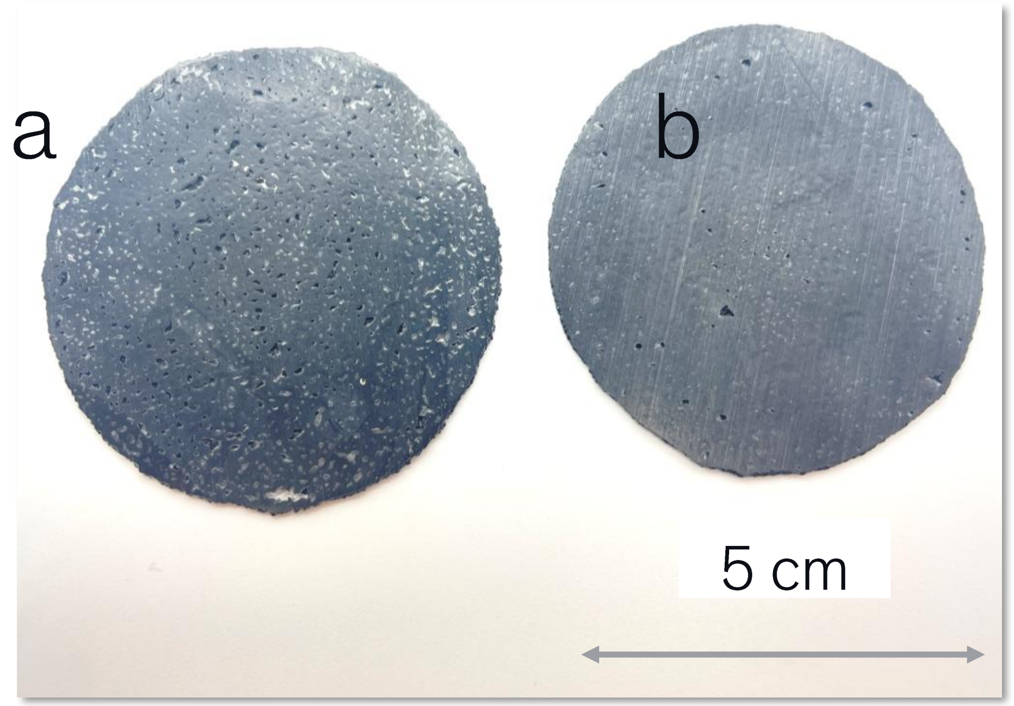
Thermal and chemical reduction of graphene oxide in polyamide composites



Residual mass after melting at 230 °C. Mass loss is linearly proportional to GO concentration and decreased by pre-reduction with ascorbic acid.



Volume resistivity of plates. Since thermal reduction have occured, the effect of ascorbic acid is less prominent compared to powders.



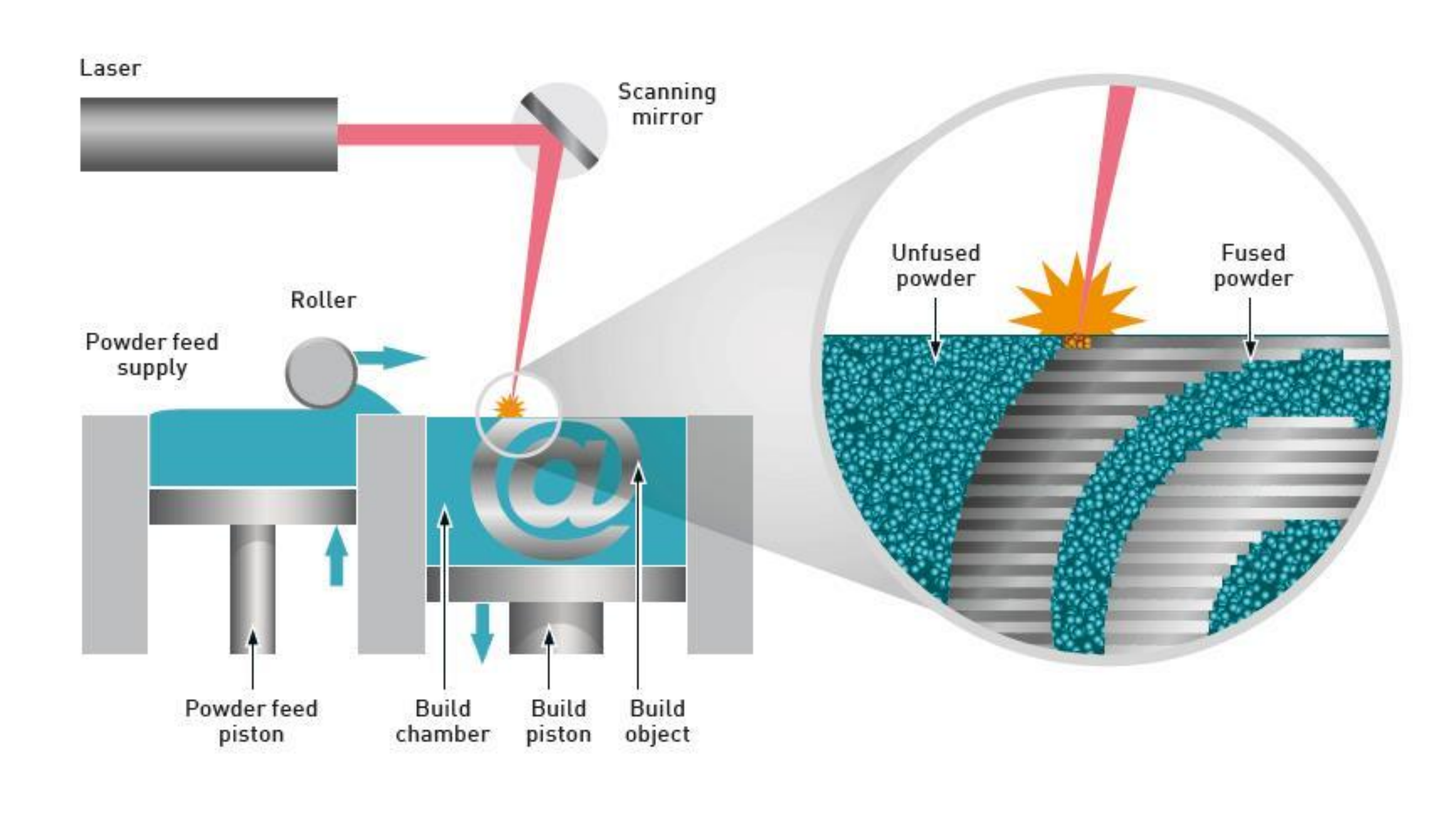
Photographs of plates of powder containing 10 wt% GO. b) is pre-reduced with ascorbic acid resulting in lower porosity.

Conclusions

- During melting of PA-GO composite powder, GO is thermally reduced and the subsequent gas evolution may lead to voids in the produced part.
- Pre-reduction with ascorbic acid increases conductivity of powder and melted plates. The amount of evolved gas is decreased by pre-reduction.
- To avoid gas formation and voids in final parts of polymer composites with GO a pre-reduction step can be added.

Laser powder bed fusion (L-PBF)

- Additive manufacturing technique
- Powder-bed based
- One powder layer is melted at a time, 20-100 µm layers
- Parameters than can be changed is:
  - ➢ Layer thickness
  - ➢ In what pattern and speed the laser moves
  - ➢ Laser power



https://www.materials-talks.com/analytical-tools-for-characterizing-metal-powders-for-additive-manufacturing

→ Which materials are interesting for AM and L-PBF?

316L-graphene for hydrogen

- Idea: adding graphene materials to steel may enable enhanced resistance towards hydrogen embrittlement
- Is graphene remaining after processing?
- Changes in microstructure?
- PBF and Hot Isostatic Pressing (HIP) manufacturing

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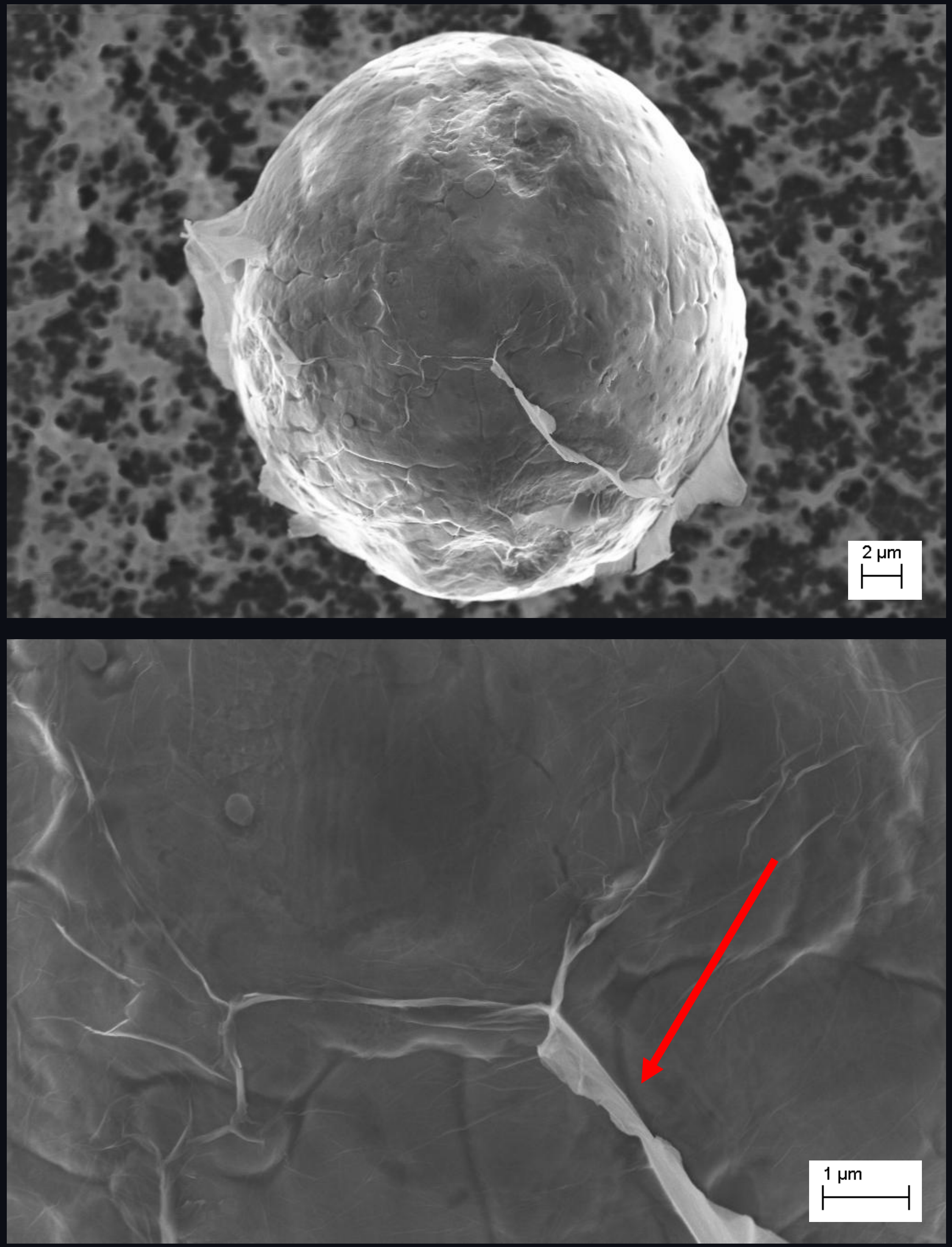
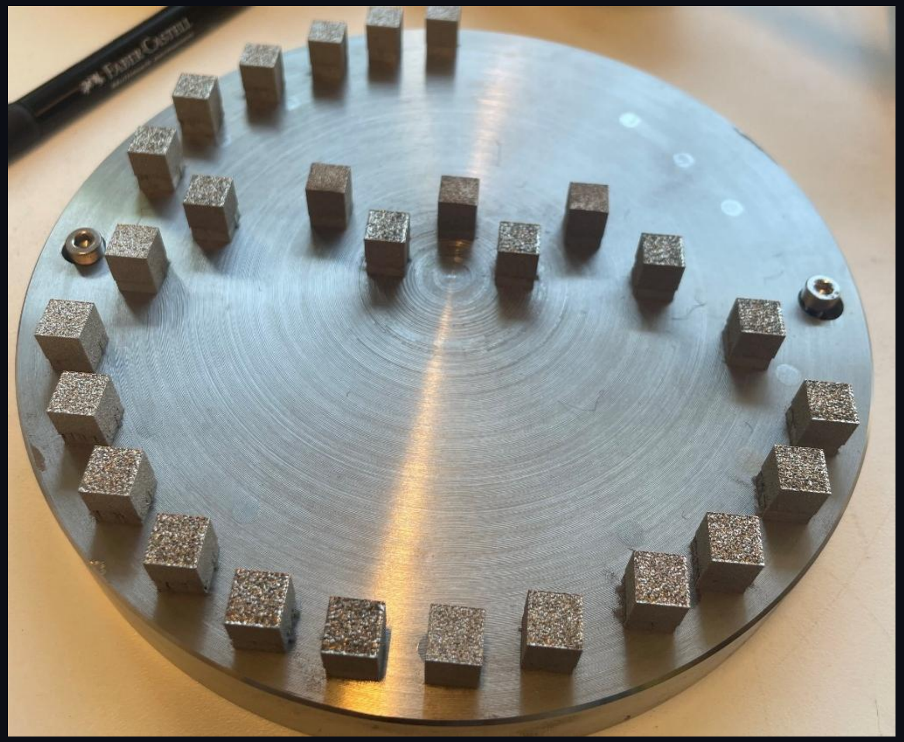
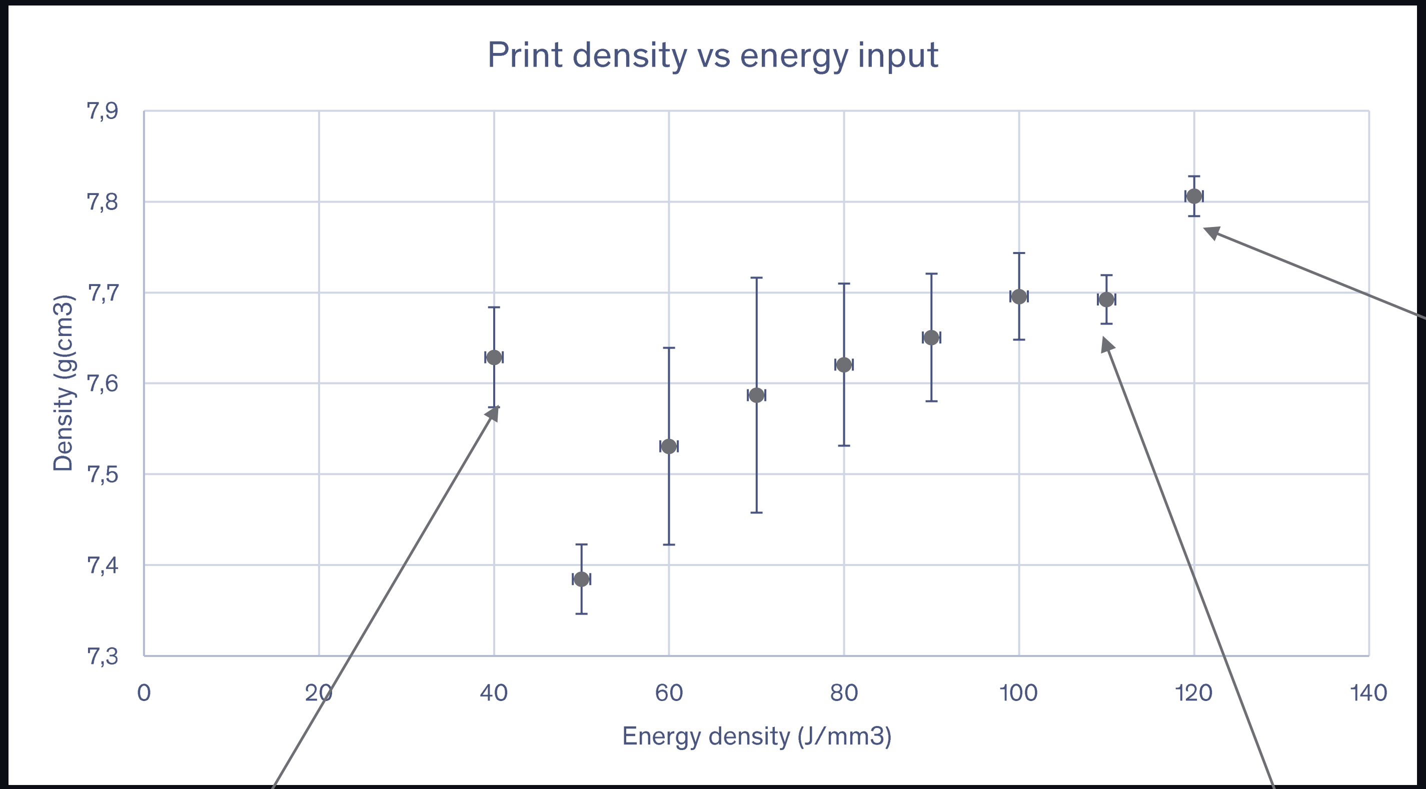
MTC PS



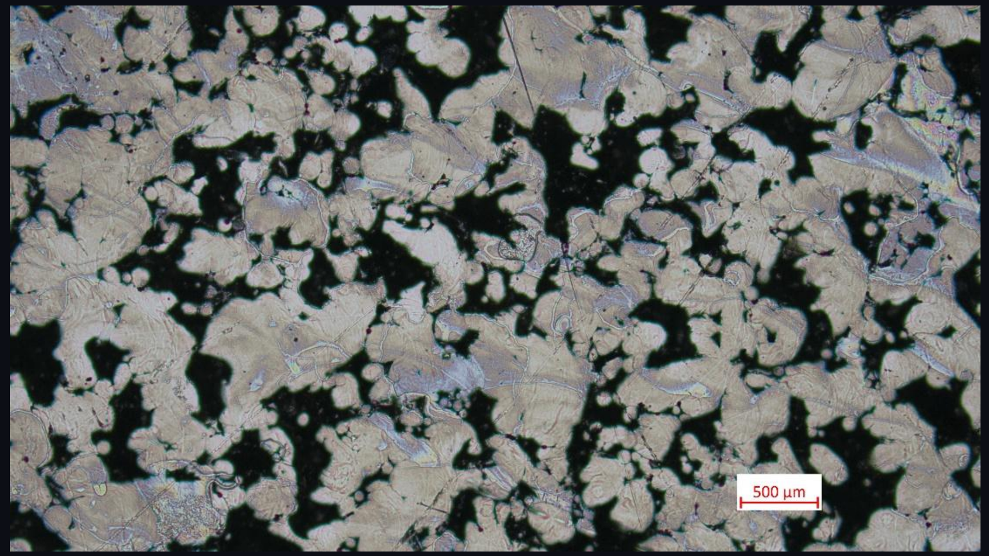
316L powder coated with graphene oxide

Print trials with 316L-GO

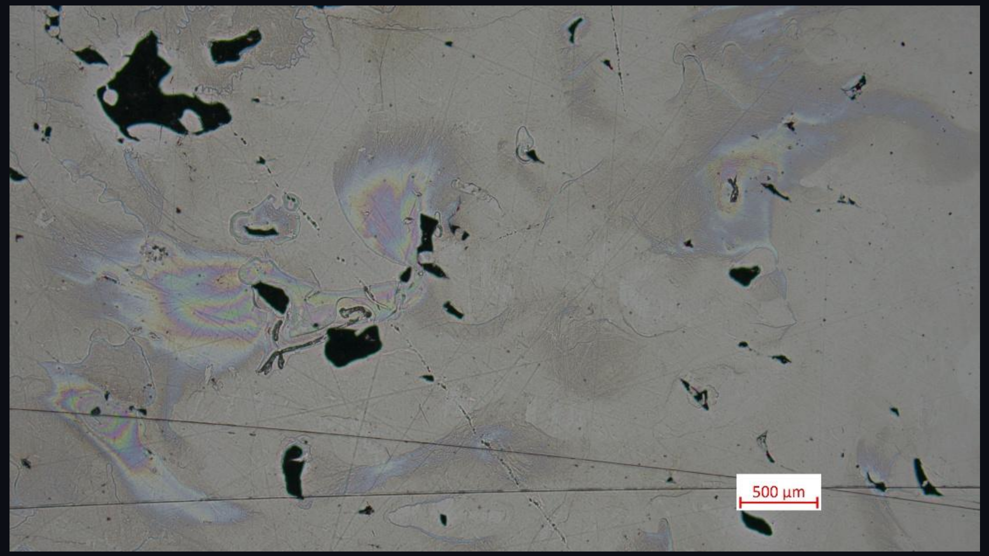




120 J/mm3 (230 W) (not polished)



40 J/mm3 (77 W)



110 J/mm3 (211 W)

Next steps

- Optimize printing parameters
- Produce parts using Hot Isostatic Pressing (HIP)
- Characterize mechanical properties and evaluate hydrogen embrittlment with and without graphene

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Thankyou for your attention!

Wallenberg Initiative
Materials Science
for Sustainability

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Knut och Alice
Wallenbergs
Stiftelse

AROS SLS PA11 ESD

World's first graphene engineered SLS powder launched in 2024!

Information video:

https://www.youtube.com/watch?v=GCcWj_EvToE

Technical data sheet:

graphmatech.com/en/files/aros-sls-pa11-esd


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TECHNICAL DATA SHEET

AROS SLS PA11 ESD

PA11-graphene powder for SLS

AROS SLS PA11 ESD is a Polyamide 11 (PA11) powder enhanced by our Aros Graphene® Technology, with electrostatic discharge (ESD) properties.

This unique graphene-engineered powder gives homogeneous properties in all print directions, makes the parts denser than neat PA11, and decreases dusting, amongst other improvements.

IMPROVED PROCESSABILITY →

- 2 × less post-processing time
- Increased flowability
- Powder is anti-static
- Decreased dusting
- Easy to print

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THE WORLD'S FIRST GRAPHENE ENGINEERED SLS POWDER.

Graphmatech AB | sales@graphmatech.com | graphmatech.com

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Polymers to maximize hydrogen potential

Meet us in the booth or contact us at sales@graphmatech.com!

Learn more at https://graphmatech.com/en