Co-funded by the Erasmus+ Programme of the European Union

AM Polymer Materials and Properties

Tuesday 1st June 2021

Got a question ?
Please use the "**chat"** or **"raise your hand"** functions

AM Polymer Materials and Properties

- This pilot course is organised under the scope of the **Sector Skills Strategy in Additive Manufacturing (SAM) Project**
- Running from 1st Jan 2019 – 31st Dec 2022
- European-wide consortium with 17 partners comprising:
  - Industries
  - Education and Training Providers

This project has been funded with support from the European Commission. This communication reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

AM Polymer Materials and Properties

- **<u>Some objectives of the SAM Project</u>**
  - Assess and anticipate skills (gaps and shortages) in AM
  - Develop an International AM Qualification System (IAMQS)
  - Raise awareness of AM and increase the attractiveness of the sector to young people
  - Train and track students, trainees and job seekers in AM

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AM Polymer Materials and Properties

- **Sector Skills Strategy in Additive Manufacturing (SAM) Project**

Website: http://www.skills4am.eu/

Twitter: https://twitter.com/skills4am

YouTube: https://www.youtube.com/channel/UCO-PfDXv5ReiELtkvyVbtHA

Facebook: https://www.facebook.com/SectorSkillsStrategyinAdditiveManufacturing/

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AM Polymer Materials and Properties

- **Sector Skills Strategy in Additive Manufacturing (SAM) Project**

SAM general group on LinkedIn:
https://www.linkedin.com/groups/12231279/

Students, Trainees & Jobseekers in AM
https://www.linkedin.com/groups/8918566/

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Meet your lecturers

Dr Adeayo Sotayo

- BEng Mechanical Engineering, University of Liverpool, UK
- PhD Engineering, Lancaster University, UK
- Research Fellow and Associate Lecturer, University of Liverpool, UK
- **Research Fellow and Chartered Engineer, Brunel University, UK**

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Meet your lecturers

Dr Claes Fredriksson

- MSc and PhD in Physics at Linköping University, Sweden
- About 20 years teaching experience in materials (e.g. metals, polymers) and sustainability, around the world
- **Associate Professor of Materials Science**
- **Lead Education Development Manager, Ansys Materials Business Unit, UK**

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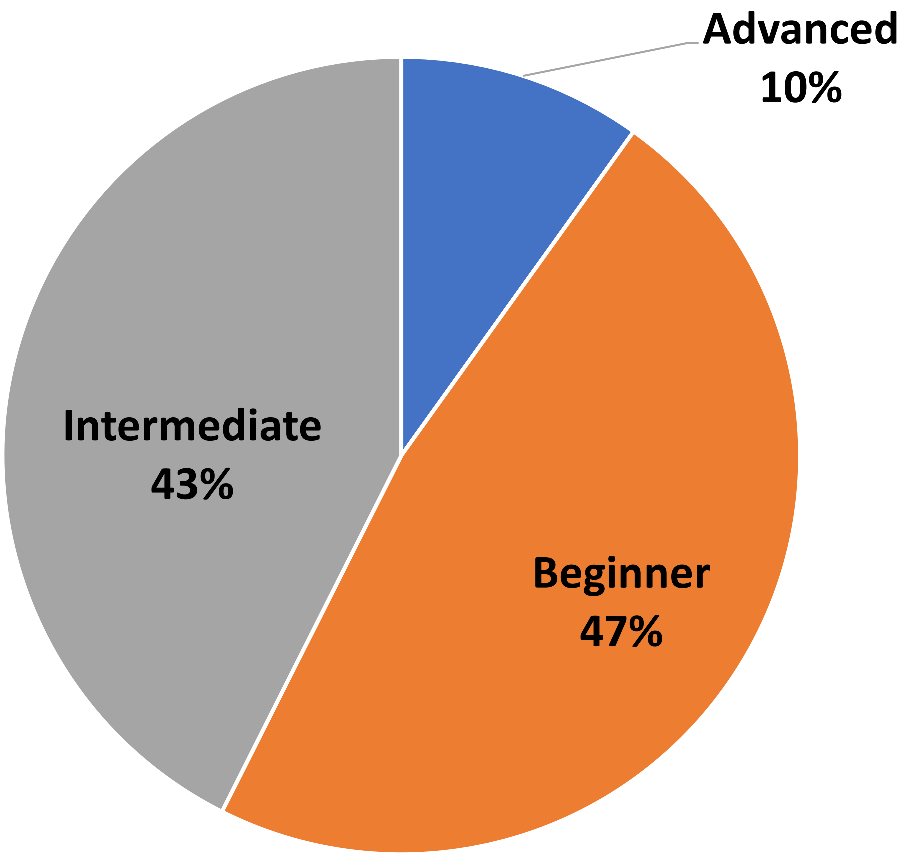
Participants' knowledge of Materials



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Quiz time – What are you hoping to get out of this course?

Website – [Vevox.app]

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Learning Outcomes

1. List different polymers used in AM

2. Explain different AM processes used for polymer materials

3. Describe the properties (e.g., mechanical properties) of AM polymers

4. Explain the effect of processing and environmental conditions (e.g., temperature) on AM polymers

5. Identify different applications of AM polymers (e.g., Automotive, Aerospace, Biomedical etc.)

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Teaching structure

Week	Topic	Lecturer
1A Tuesday 1st June 2021 2hr lecture (10am – 12pm BST)	**Introduction to Polymer Materials in AM – Examples and Properties**	AS and CF
1B Wednesday 2nd June 2021 2hr lecture (10am – 12pm BST)	**Polymer Materials in AM – Case Study**	AS and CF
2A Monday 7th June 2021 7-minute assessment (10am – 10:30am BST)	**Assessment**	AS
TBC (approximately a week after)	**Assessment (Resit)**	AS

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Assessment

- At the end of the course, participants will need to complete the **assessment (7th June 2021 – seven questions)** for this course, which are based on:
  - Learning outcomes
  - Lecture slides
  - Other teaching resources (shared).
- Participants **must attend the lectures (x2),** complete **feedback surveys** and get a **minimum of 60%** in the assessment to be eligible for the **certificate of attendance** by the **SAM project**.

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Let's get started

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Introduction to Polymer Materials in AM (Examples and Properties)

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What is AM

Additive Manufacturing (also called 3D Printing)

- ✓ Design a 3D model of an object/product using a computer software
  - ❖ *Free CAD examples include TinkerCAD, SketchUp*
- ✓ Builds the object by adding (not subtracting) materials layer by layer

Source: giphy.com

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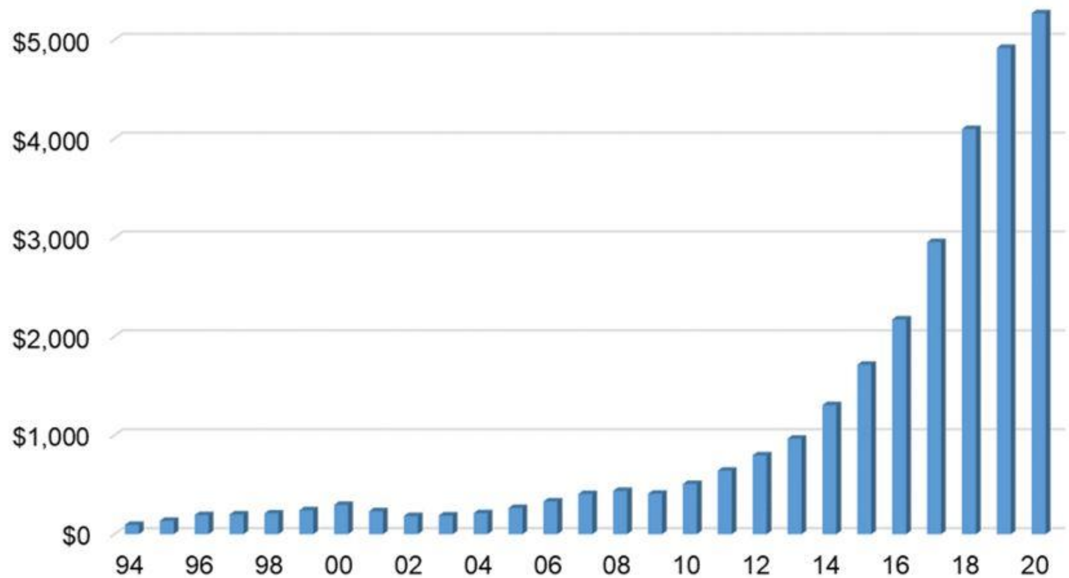
AM Industry

- ✓ Continuous growth
- ✓ **7.5% growth** to **$12.8 billion** in 2020 (despite COVID-19 Pandemic)
- ✓ Growth was down compared to average growth of **27%** in previous 10 years



Production of AM parts from independent service providers (in millions of dollars). Source: Wohlers Report 2021

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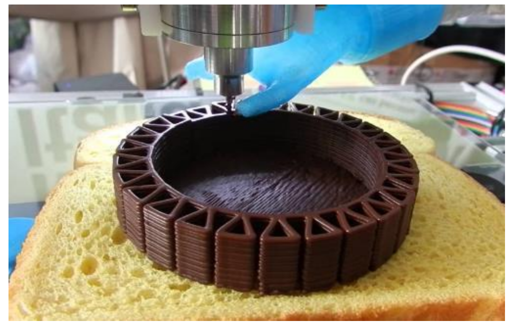
Additive Manufacturing across different sectors

Construction

Source: m-tec (2020)

Food

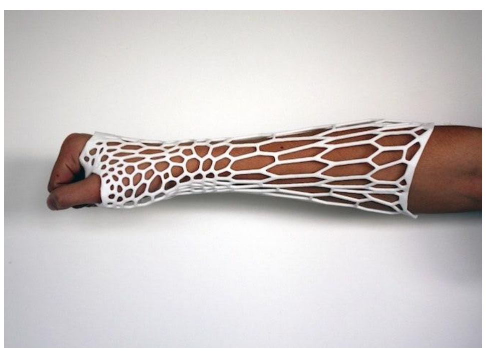


Source: Fabbaloo (2018)

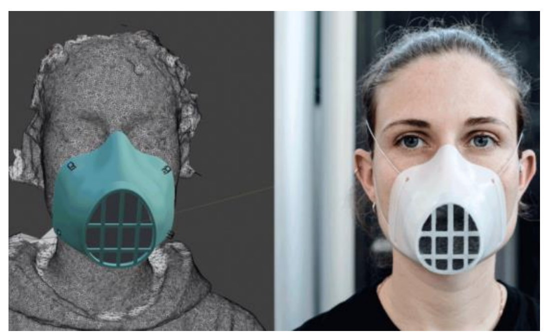
Aerospace/Automotive

Source: AMFG.ai (2019)

Health & Biomedical



Source: Pixabay (2020)



Source: 3D Printing Media Network (2020)

Source: Shutterstock (2020)

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Why AM

- ✓ **Less waste**
  - ❖ Use the right amount of amount of material with little or no material wasted
- ✓ **Customisation**
  - ❖ Each design can be different, and suited to what you want
- ✓ **Complex geometries**
  - ❖ AM creates complex designs compared to traditional types of manufacturing
- ✓ **Fast production**
  - ❖ 3D Printing can make objects within a minutes or hours (depending on the complexity)
  - ❖ You need the **3D Model** and a **3D Printer**

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Seven AM processes by ISO/ASTM 52900:2015

- Material extrusion
- Material jetting
- Binder jetting
- Directed energy deposition
- Powder bed fusion
- Sheet lamination
- Vat photopolymerization

Underlined processes is typically used to make AM polymers

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Material extrusion

Material is selectively dispensed through a nozzle

Technology

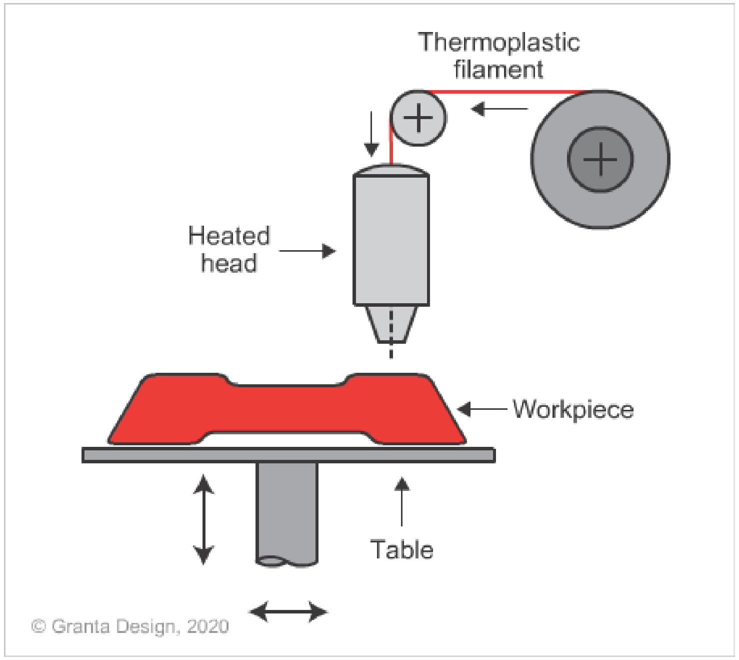
- ✓ Fused Deposition Modelling (FDM)
- ✓ Fused Filament Fabrication (FFF)

Features

- ✓ Very popular
- ✓ Relatively cheap and economical
- ✓ Can be used at home or in the office
- ✓ Availability in multiple colours

Typical materials

- ✓ Thermoplastic filaments



Ansys Granta
https://www.grantadesign.com/education/teachingresources/ongoing-development/additive-manufacturing/

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Material jetting

Droplets of build material are selectively deposited

Technology

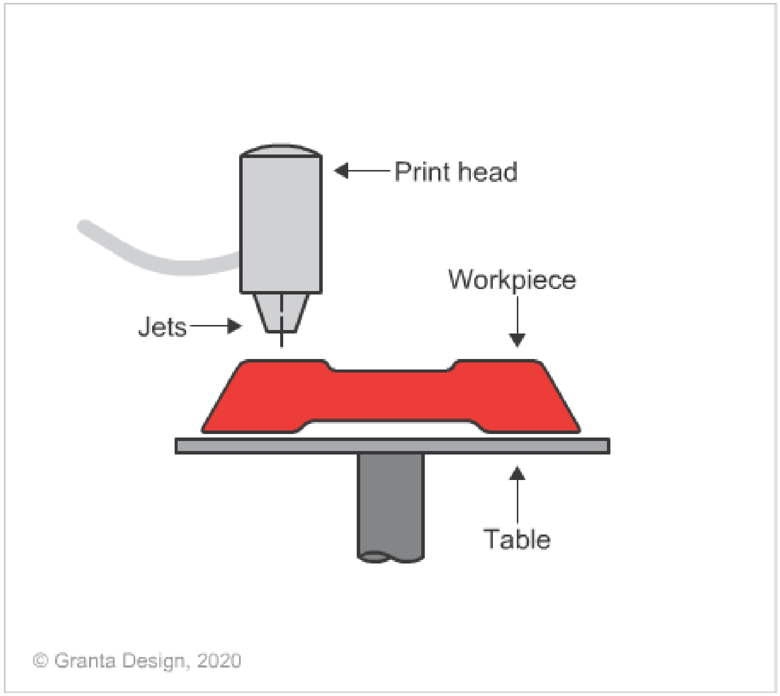
- ✓ Multi-Jet Modelling (MJM)
- ✓ Drop on Demand (DOD)

Features

- ✓ High accuracy of deposition of droplets and therefore low waste
- ✓ Multiple material parts and colours

Typical materials

- ✓ Photopolymers, Polymers (resin), Waxes



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Binder jetting

Liquid **bonding agent** is selectively deposited to join **powder** materials

Technology

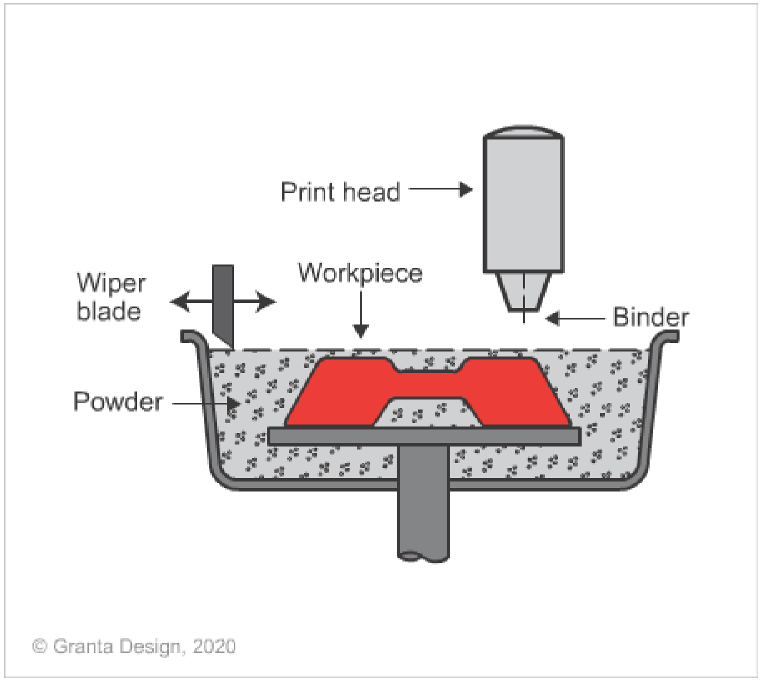
- ✓ Drop on Powder (DOP)
- ✓ Powder Bed printing

Features

- ✓ Wide range of materials in powder form
- ✓ Relatively fast process

Typical materials

- ✓ Polymer powder, metal powder, ceramic powder, gypsum powder, sand.



Ansys Granta
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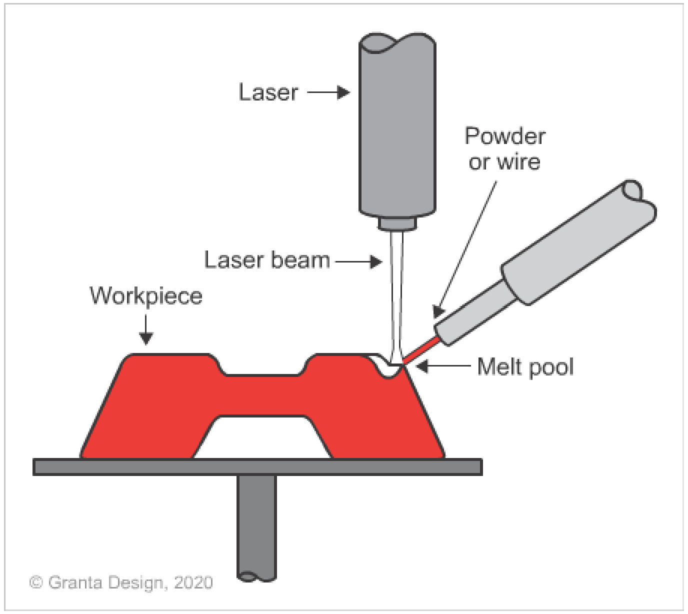
Directed energy deposition (DED)

Thermal energy (laser or electron beam) is used to fuse materials by melting as they are being deposited



Technology

- ✓ Laser Metal Deposition (LMD)
- ✓ Laser Engineered Net Shaping (LENS)
- ✓ Direct Metal Deposition (DMD)
- ✓ Electron Beam Free-Form Fabrication (EBF3)

Features

- ✓ Effective for repairs and adding features
- ✓ Limited material use

Typical materials

- ✓ Metal wire or powder (no polymers)

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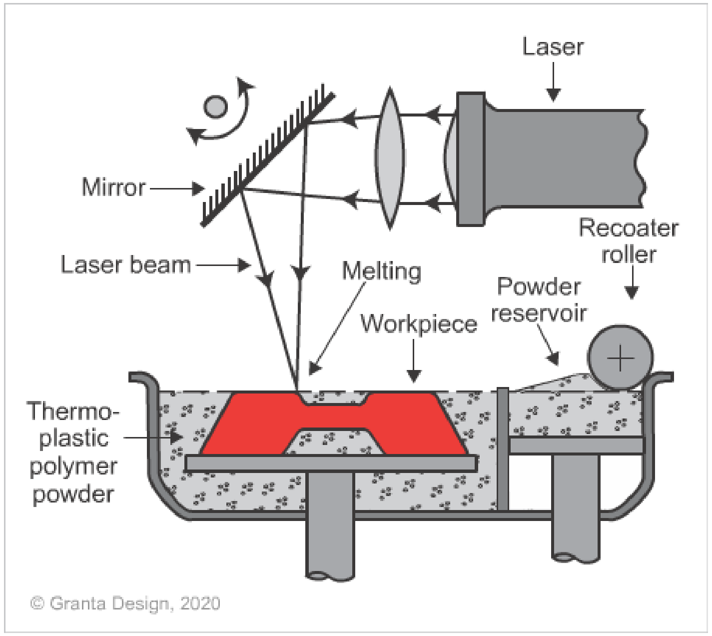
Powder bed fusion (PBF)

Thermal energy (laser or electron beam) selectively fuses regions of a powder bed



Technology

- ✓ Selective Laser Sintering (SLS)
- ✓ Selective Heat Sintering (SHS)
- ✓ Direct Metal Laser Sintering (DMLS)
- ✓ Electron Beam Melting (EBM)
- ✓ Selective Laser Melting (SLM)

Features

- ✓ Wide range of materials, cost-effective, powder acts as support material

Typical materials

- ✓ Polymer (e.g. nylon powder), metal and ceramic powder

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Sheet lamination

Sheets of material are bonded to form a part

Technology

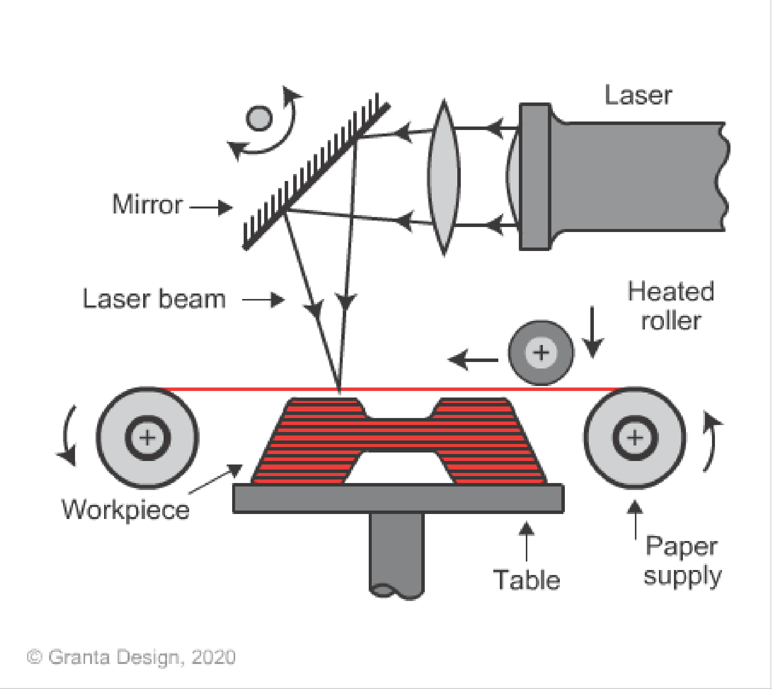
- ✓ Selective Deposition Lamination (SDL)
- ✓ Laminated Object Manufacturing (LOM)
- ✓ Ultrasonic Additive Manufacturing (UAM))

Features

- ✓ Cost-effective and relatively fast

Typical materials

- ✓ Polymer sheets, metal sheets



Vat photopolymerization

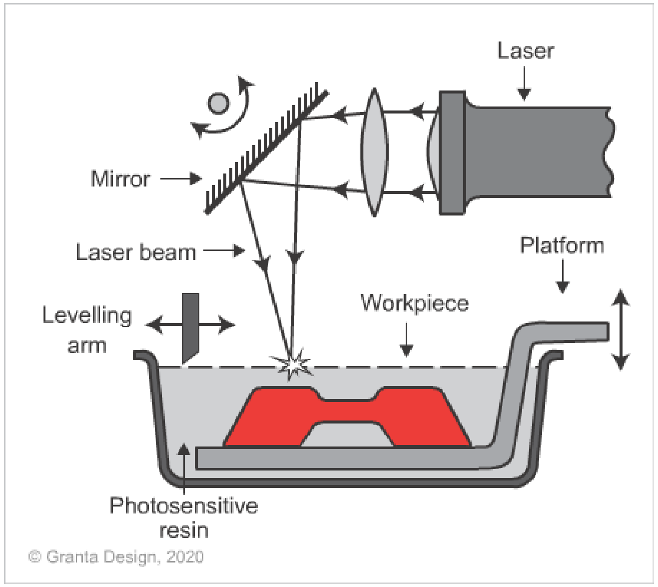
Liquid photopolymer in a vat is selectively cured by light-activated polymerization

Technology

- ✓ Stereolithography (SLA)
- ✓ Digital Light Processing (DLP)
- ✓ Continuous Liquid Interphase Production (CLIP)
- ✓ Scan, Spin, and Selectively Photocure (3SP)

Features

- ✓ High accuracy and complexity
- ✓ Excellent surface finish and high resolution
- ✓ Relatively fast, costly and large build areas
- ✓ Lengthy post-processing time



Typical materials

- ✓ Photopolymer resins, acrylics and epoxies

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Quiz time – Which of these AM processes entails selectively depositing droplets of the build material (e.g. polymer resin)?

Website – Vevox.app

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Quiz time – Which of these AM processes provides the best surface finish?

Website – Vevox.app

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Why use polymers in AM

- ✓ Low cost
- ✓ Ease of manufacture
- ✓ Variety and versatility
- ✓ Ability to combine with fibres to form stronger composite materials
- ✓ Availability in filament, powder and resin forms

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Challenges with using polymers

- ✓ Growing environmental concern
- ✓ Most polymers are derived from non-renewable petrochemicals
- ✓ However, polymers from renewable materials (e.g. PLA) are becoming increasingly popular

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Common polymers used in AM

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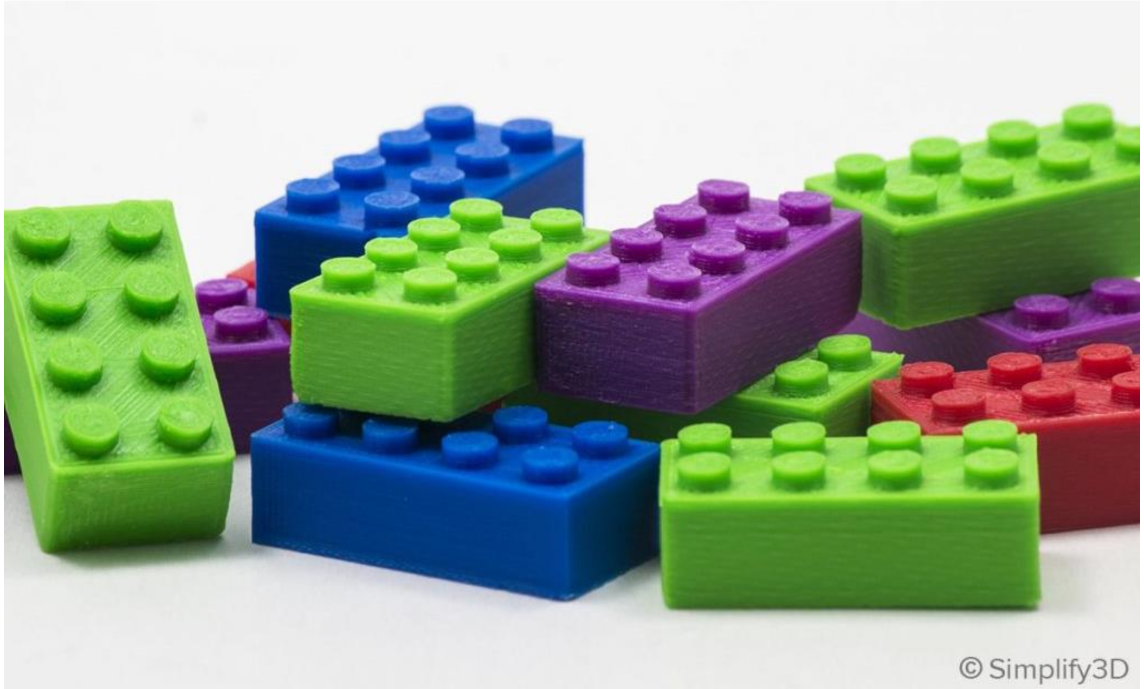
Acrylonitrile Butadiene Styrene (ABS)

Applications

- ✓ Household items, toys (e.g. LEGO), automotive components, pipe fittings, prototypes



Simplify3D (2021) - https://www.simplify3d.com/support/materials-guide/abs/

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Acrylonitrile Butadiene Styrene (ABS)

Properties and AM Processing Parameters

- ✓ Available in **filaments form for FDM**, **powder form for SLS** and **liquid form for SLA**
- ✓ Tough material and good impact properties
- ✓ Processing temperature **(230 - 260 °C)**
- ✓ Heated platform **(85 - 130°C)** to prevent warping
- ✓ AM machine with an enclosed chamber is preferable because it emits potentially dangerous particles and unpleasant fumes

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Polylactic acid or polylactide (PLA)

Applications

✓ Food packaging, decorative items, plastic bags, bottles, plastic sheets and films

3D natives (2021)
https://www.3dnatives.com/en/pla-3d-printing-guide-190820194/

Simplify3D (2021)
https://www.simplify3d.com/support/materials-guide/pla/

Polylactic acid or polylactide (PLA)

Properties and AM Processing Parameters

- ✓ Made from renewable sources (e.g.. corn starch, maize, sugarcane)
- ✓ Biodegradable
- ✓ Simple and easy to 3D Print
- ✓ Processing temperature **(190 °C - 230 °C)** (lower than ABS)
- ✓ No heated platform required (unlike ABS) because it doesn't warp easily.

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Polyethylene terephthalate (PET)

Applications

- ✓ Plastic bottles and packaging, electrical fittings and connectors

3D natives (2020)
https://www.3dnatives.com/en/plastics-used-3d-printing110420174/#!

Simplify3D (2021)
https://www.simplify3d.com/support/materials-guide/petg/

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Polyethylene terephthalate (PET)

Applications

- ✓ Plastic bottles and packaging, electrical fittings and connectors

Properties and AM Processing Parameters

- ✓ Good impact and chemical resistance, dimensional stability
- ✓ Other variants such as PETG (Glycol modified version of PET).
- ✓ PETG has relatively reduced brittleness and fragility and easier to 3D print
- ✓ Processing temperature **(220 - 260 °C)** and platform bed temperature **(75 - 90°C)**
- ✓ Odourless during processing and highly recyclable

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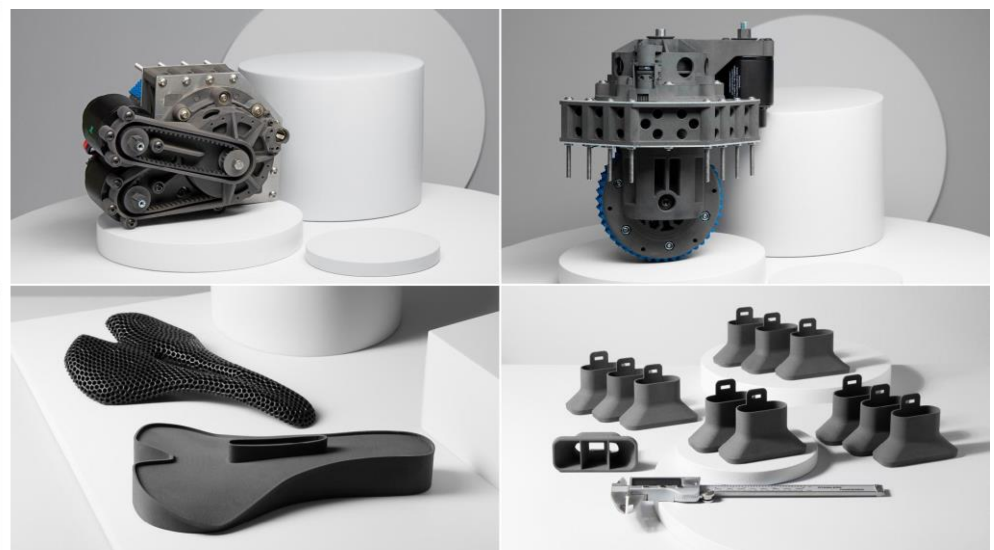
Nylon or Polyamide (PA)

Applications

✓ Functional parts, automotive and aerospace components (e.g. gears, bearings), medical prosthetic devices

Simplify3D (2021)
https://www.digitaltrends.com/cool-tech/formlabs-fuse1-sls-printer-news/



Formlabs (2021)
https://ourdailysigns.com/formlabs-expands-additive-manufacturing-attain-with-fuse-1-sls-printer/

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Nylon or Polyamide (PA)

Properties and AM Processing Parameters

- ✓ Good stability, rigidity and high impact resistance
- ✓ No unpleasant odour during manufacturing
- ✓ Processing temperature **(225 - 265 °C)** and platform bed temperature **(70 - 90°C)**
- ✓ Available in **filaments form** for **FDM**, and **powder form** for **SLS**

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Polypropylene (PP)

Applications

- ✓ Automotive sector, pipes and fittings textiles industry, everyday products, garden furniture, cups

3D natives (2020) https://www.3dnatives.com/en/polypropylene-pp-for-3d-printing-160720204/

Sculpteo (2021) https://www.sculpteo.com/en/3d-learning-hub/3d-printing-materials-guide/3d-printing-polypropylene/

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Polypropylene (PP)

Applications

- ✓ Automotive sector, textiles industry, everyday products, garden furniture, cups

Properties and AM Processing Parameters

- ✓ Good impact and fatigue resistance
- ✓ Sensitive to UV rays causing it to expand and low temperature resistance (warping during cooling)
- ✓ Processing temperature **(220 - 250 °C)** and platform bed temperature **(85 - 100°C)**

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Polyvinyl Alcohol (PVA)

Simplify3D (2021) https://www.simplify3d.com/support/materials-guide/pva/

Applications

- ✓ Typically printed as a support material complex AM designs and products (e.g. overhangs)

Properties and AM Processing Parameters

- ✓ Soft and biodegradable polymer
- ✓ Highly sensitive to moisture (dissolves in water) – useful as support structure material
- ✓ Processing temperature **(185 - 200 °C)** and no heated platform required

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Thermoplastic Elastomers (TPE) and Thermoplastic polyurethane (TPU)

Applications

✓ Vibration dampening, deformable products, fashion industry (e.g. shoe soles), car wheels.

All3DP (2020)
https://all3dp.com/1/3d-printer-filament-types-3d-printing-3d-filament/

3D natives (2020)
https://www.3dnatives.com/en/tpu-3d-printing-040620204/

3D natives (2020)
https://www.3dnatives.com/en/tpu-3d-printing-040620204/

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Thermoplastic Elastomers (TPE) and Thermoplastic polyurethane (TPU)

Properties and AM Processing Parameters

- ✓ Flexible materials, good impact resistance and excellent vibration dampening
- ✓ Difficult to 3D Print accurately
- ✓ Processing temperature **(225 - 245 °C)** and no heated platform required

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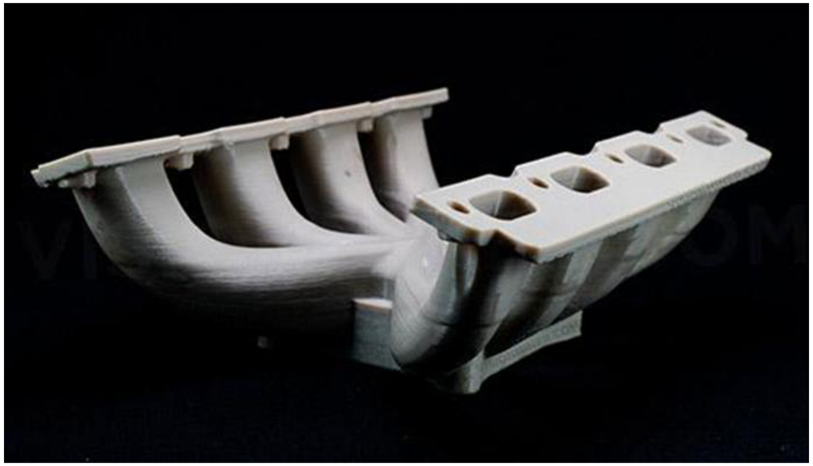
High Performance Polymers

Polyether ketone ketone (PEKK), Polyether ether ketone (PEEK), Polyetherimide (PEI)

Applications

✓ Aerospace, automotive (e.g. engine components, electrical housing), oil and gas, and medical sectors (e.g. medical implants)

ApiumTec and 3D natives (2019)
https://www.3dnatives.com/en/3d-materials-peek-ultem-170120194/#!



3D natives (2019)
https://www.3dnatives.com/en/3d-materials-peek-ultem-170120194/#!

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High Performance Polymers

- ✓ Polyether ketone ketone (PEKK)
- ✓ Polyether ether ketone (PEEK)
- ✓ Polyetherimide (PEI)

Properties and AM Processing Parameters

- ✓ Excellent mechanical, chemical and thermal properties
- ✓ Typically more expensive than other polymers
- ✓ Heated platform **(~ 230 °C),** processing temperature **(~ 350 °C)** and closed chamber
- ✓ Available in **filaments form** for **FDM**, and **powder form** for **SLS**

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Quiz time – Which of these Polymers is NOT typically made using Additive Manufacturing?

Website – Vevox.app

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Quiz time – Which is of these AM Polymers is classified as a high-performance polymer due to greater mechanical and thermal properties?

Website – [Vevox.app]

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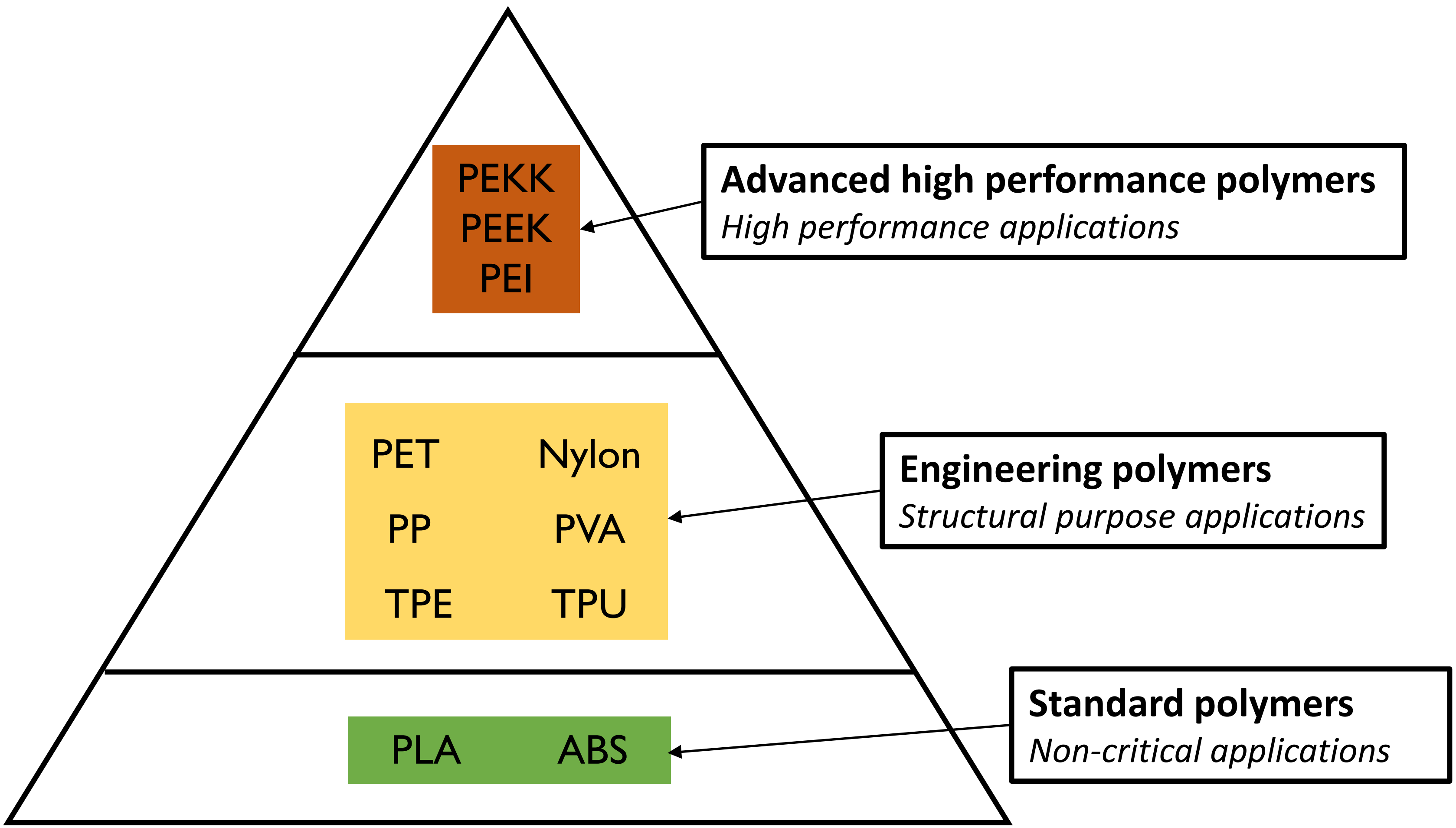
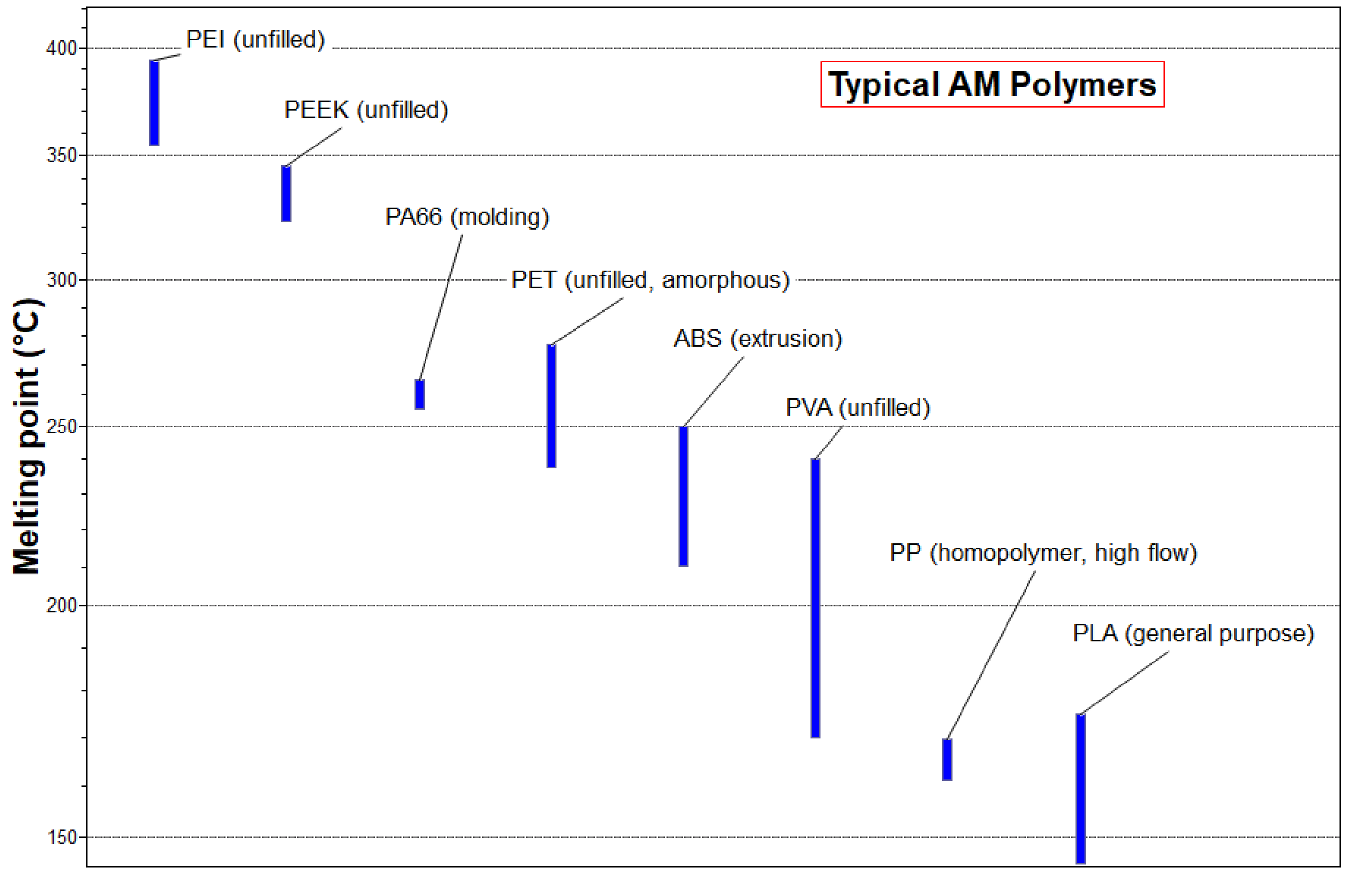
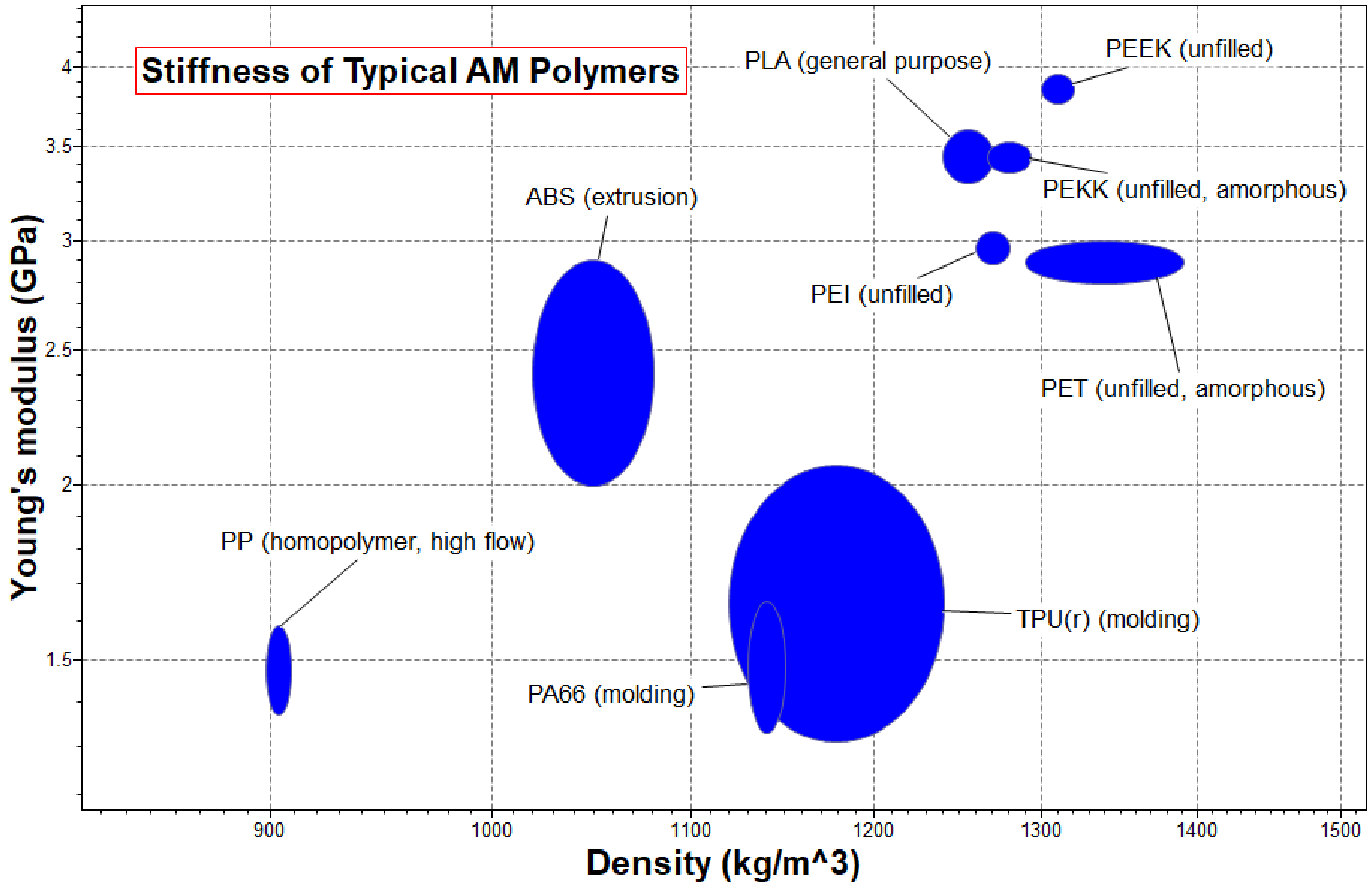


Adapted from 3D natives (2020) https://www.3dnatives.com/en/peek-3d-printing-060420204/

Thermal properties



Mechanical properties



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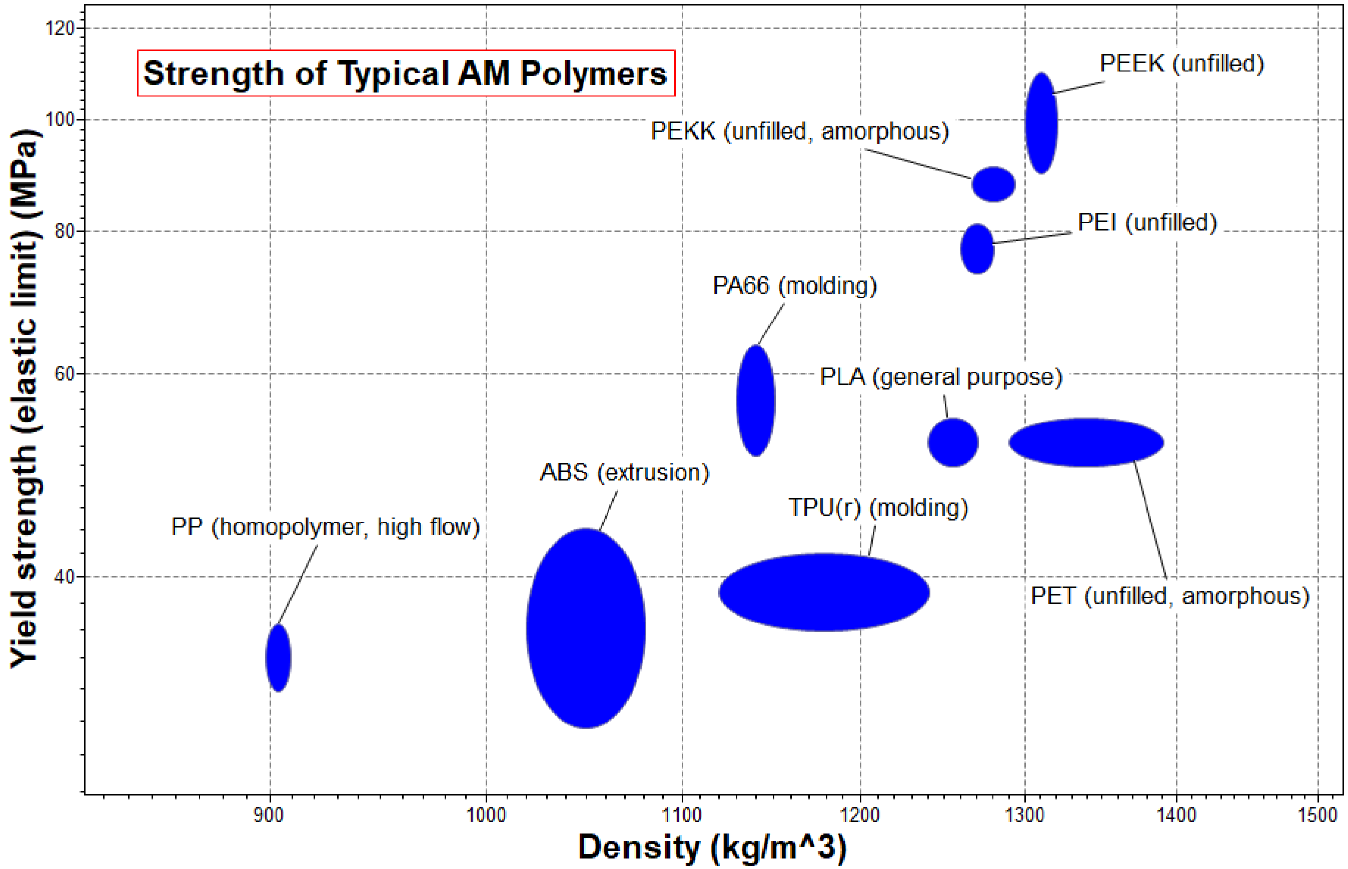
Mechanical properties



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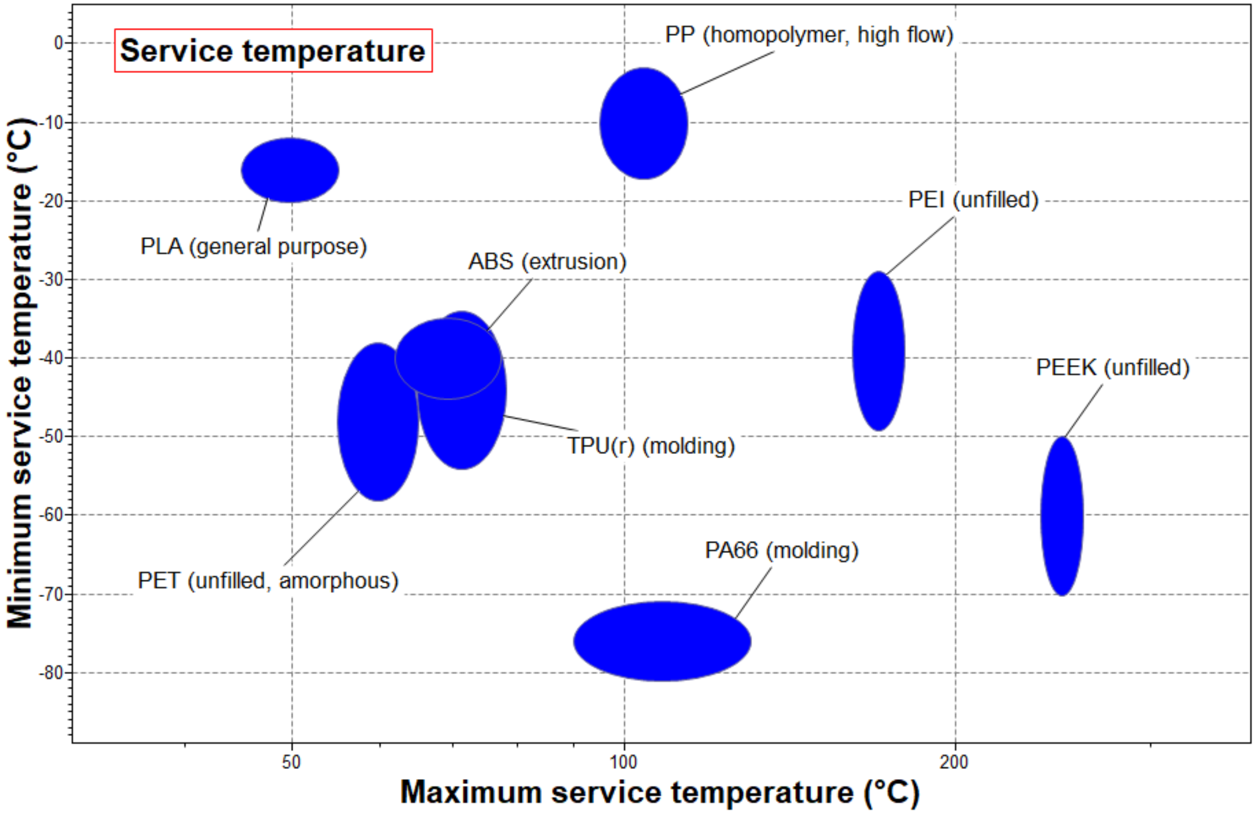
Max and min service temperatures



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Mechanical properties

Several factors affect the mechanical properties of additive manufactured polymers:

- ✓ Material Properties of the unprinted polymer
  - ❖ Several types
  - ❖ New or recycled
- ✓ AM Manufacturing Process
  - ❖ Several processes
  - ❖ Printing parameters (e.g., processing temperature, curing time)
  - ❖ AM equipment
  - ❖ Reinforcements and fillers to enhance the properties
- ✓ Post-processing techniques

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Mechanical properties

Additional notes

✓ Limitations of Material extrusion (i.e. FDM) include:

- ❖ Mechanical anisotropy (~ 50%) can lead to weaker parts/products
- ❖ Part-to-part variations

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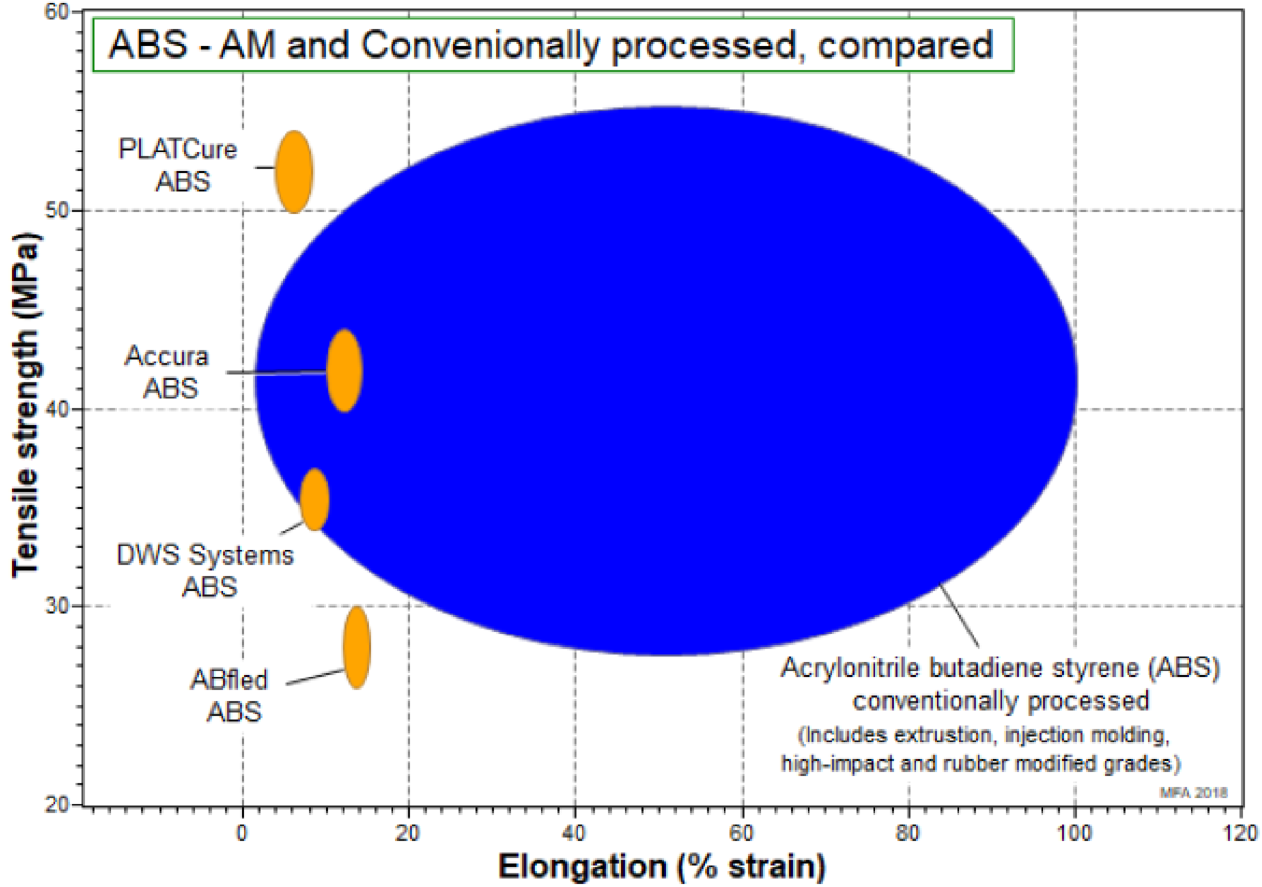
Mechanical properties



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Mechanical properties

Material	Process	Manufacturer	Tensile strength [MPa]	Tensile modulus [GPa]
ABS	SLA (Stereolithography)	3D systems	48	2.6
ABS	FDM (Material extrusion)	Stratasys	26	2.2

Data obtained from Kazmer, D., 2017. Three-dimensional printing of plastics. In Applied Plastics Engineering Handbook (pp. 617-634). William Andrew Publishing.

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Mechanical properties

Material	Process	Manufacturer	Tensile strength [MPa]	Tensile modulus [GPa]
Nylon	SLS (Powder bed fusion)	EOS	48	1.7
Nylon with glass beads	SLS (Powder bed fusion)	EOS	51	3.2
Nylon with aluminium (Alumide)	SLS (Powder bed fusion)	EOS	48	3.8
PEEK	SLS (Powder bed fusion)	EOS	90	4.2

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Quiz time – Which of these factors can affect the mechanical and thermal properties of AM polymers?

Website – Vevox.app

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Recap

1. List different polymers used in AM

2. Explain different AM processes used for polymer materials

3. Describe the properties (e.g., mechanical properties) of AM polymers

4. Explain the effect of processing and environmental conditions (e.g., temperature) of AM polymers

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Teaching Resources

- Lecture slides
- Recording
- Further Reading

➢ 3Dnatives. 2020. **3D Printing Materials Guide: Plastics**. [online] Available at: <https://www.3dnatives.com/en/plastics-used-3d-printing110420174/> [Accessed 23 April 2021].

➢ AMFG. 2019. **3D Printing with Polymers: All You Need to Know in 2021**. [online] Available at: <https://amfg.ai/2019/01/17/3d-printing-with-polymers-all-you-need-to-know/> [Accessed 23 April 2021].

➢ Ashby, M.F., Jones, D.R. and Jones, D.R.H., 1994. **An introduction to microstructures, processing and design**. Pergamon Press.

➢ Callister Jr, W.D. and Rethwisch, D.G., 2020. **Fundamentals of materials science and engineering: an integrated approach**. John Wiley & Sons.

➢ Dizon, J.R.C., Espera Jr, A.H., Chen, Q. and Advincula, R.C., 2018**. Mechanical characterization of 3D-printed polymers**. Additive Manufacturing, 20, pp.44-67..

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Any Questions?

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Coffee Break

We will continue at 11:10am BST

AM Polymer Applications

Wednesday 2nd June 2021

Recap: AM Polymer Materials and Properties

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Teaching structure

Week	Topic	Lecturer
1A Tuesday 1st June 2021 2hr lecture (10am – 12pm BST)	**Introduction to Polymer Materials in AM – Examples and Properties**	AS and CF
1B Wednesday 2nd June 2021 2hr lecture (10am – 12pm BST)	**Polymer Materials in AM – Case Study**	AS and CF
2A Monday 7th June 2021 7-minute assessment (10am – 10:30am BST)	**Assessment**	AS
TBC (approximately a week after)	**Assessment (Resit)**	AS

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What we covered

1. An overview of AM, benefits, industry and applications across different sectors
2. Seven major AM processes and explanations
3. Polymers used in AM, benefits, and challenges
4. Properties of AM polymers
5. Factors affecting the properties of AM polymers

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Seven AM processes by ISO/ASTM 52900:2015

<u>Material extrusion</u>	• Material is selectively dispensed through a nozzle
<u>Material jetting</u>	• Droplets of build material are selectively deposited
Binder jetting	• Liquid bonding agent is selectively deposited to join powder materials
Directed energy deposition	• Thermal energy (laser or electron beam) is used to fuse materials by melting as they are being deposited
<u>Powder bed fusion</u>	• Thermal energy (laser or electron beam) selectively fuses regions of a powder bed
Sheet lamination	• Sheets of material are bonded to form a part
<u>Vat photopolymerization</u>	• Liquid photopolymer in a vat is selectively cured by light-activated polymerization

<u>Underlined processes is </u>typically used to make AM polymers

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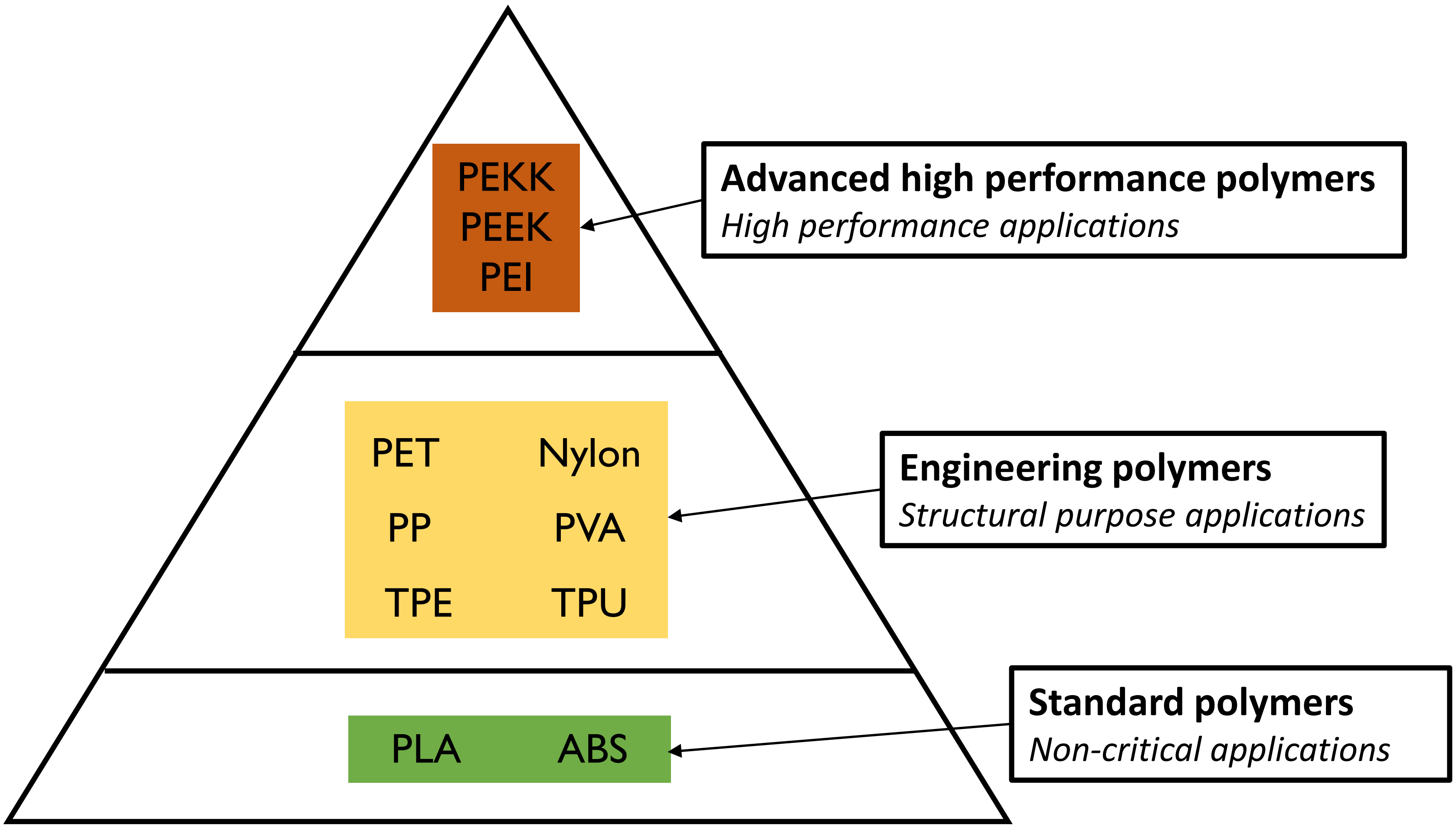
Common polymers used in AM



Adapted from 3D natives (2020) https://www.3dnatives.com/en/peek-3d-printing-060420204/

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Mechanical properties

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- ✓ Post-processing techniques

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Day 2

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Learning Outcomes day 2

1. List different polymers used in AM

2. Explain different AM processes used for polymer materials

3. Describe the properties (e.g., mechanical properties) of AM polymers

4. Explain the effect of processing and environmental conditions (e.g., temperature) on AM polymers

5. Identify different applications of AM polymers (e.g., Automotive, Aerospace, Biomedical etc.)

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Let's get started

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Brunel University London

Ansys MATERIALS

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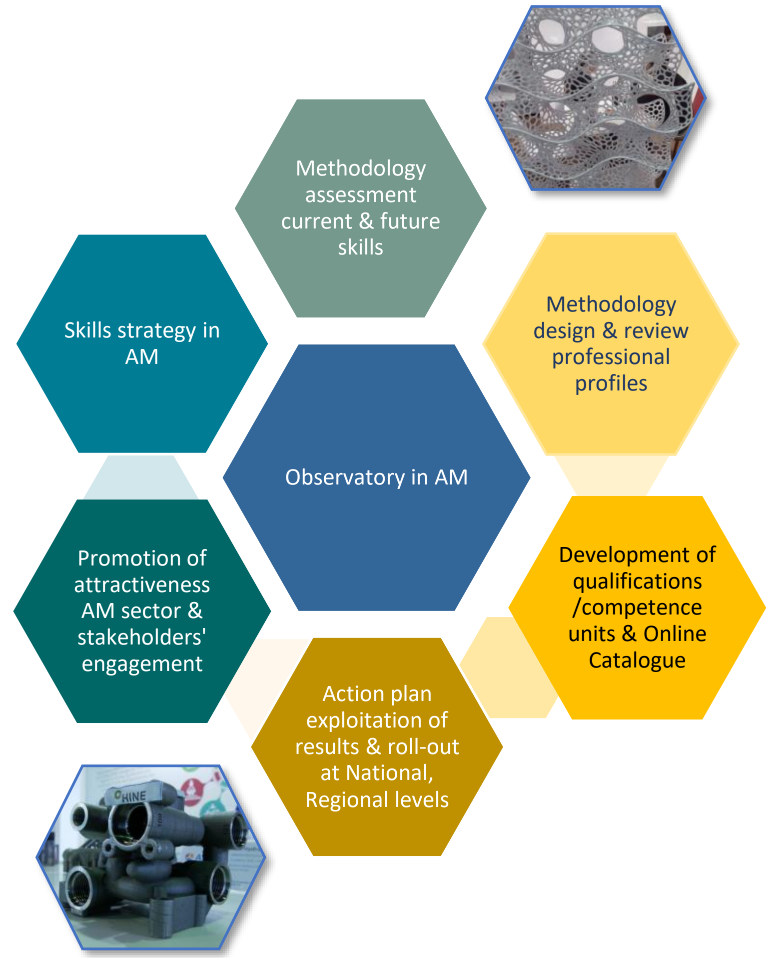
SAM project contributions from Ansys

- Development of teaching and training resources for Additive Manufacturing
- Run workshops, webinars and pilot training courses using Ansys Software for Education and Industry through outreach initiatives
- Further development of the AM modules such as interactive process descriptions, explanations and examples of process chain data types, etc
- Revise AM professional profiles
- Support project tasks and deliverables to
  - Identify and anticipate the right skills for the Additive Manufacturing (AM)
  - Develop a methodology for a sustainable and continuous assessment of current and future skills needed in AM
  - Provide solutions capable of fostering and supporting the growth, innovation and competitiveness of the AM sector



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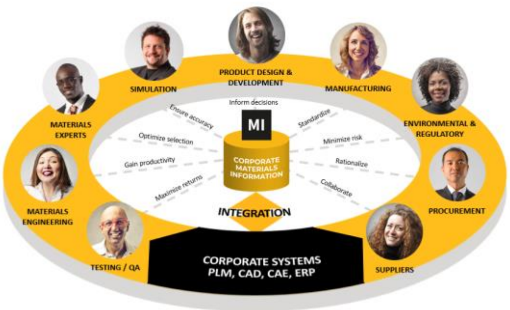
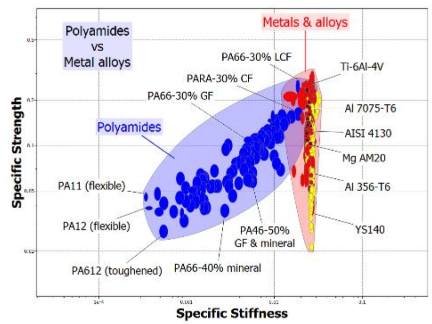
Software-based materials information and tools

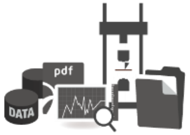


Granta MI™



Granta Selector™

Granta EduPack™



Customer's proprietary information

Comprehensive library of materials property data

Unique teaching resources

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Agenda Polymer AM Applications

- From Rapid prototyping to industrial AM
- Polymer AM vs Metal and Ceramics AM
- Polymer Matrix Composite AM

Software – examples and case studies

- Are AM Polymers any good? Microproject 1
- Sustainability of polymer AM Microproject 3
- Granta Selector – Senvol AM Database
- Online AM technology library
- Applications – overview and discussions
- Exam details?

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From Rapid prototyping to industrial AM

- **Predicted in Science Fiction 1945:**

"this constructor is both efficient and flexible. I feed magnetronic plastics — the stuff they make houses and ships of nowadays — into this moving arm. It makes drawings in the air following drawings it scans with photo-cells. But plastic comes out of the end of the drawing arm and hardens as it comes ... following drawings only"

Murray Leinster (William Fitzgerald Jenkins), in *Things Pass By*

- **Patent US3596285A: Liquid Metal Recorder 1971:**

"a continuous Inkjet **metal** material device to form a removable metal fabrication on a reusable surface for immediate use…"

Johannes F Gottwald

- **Patent JP S56-144478: XYZ plotter 1981**

"two additive methods for fabricating three-dimensional plastic models with photo-hardening thermoset **polymer**, where the UV exposure area is controlled by a mask pattern or a scanning fiber transmitter"

Hideo Kodama

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From Rapid prototyping to industrial AM

- **1980's Innovation, Individual names**

Stereolithography

Selective Laser Sintering (SLS)

Fused Deposition Modeling (FDM)

Thermoplastic Inkjet

- **1990's Commercialization, Rapid Prototyping**

E.g., Selective laser melting (SLM)

- **2000 – today, Industrialization, Additive manufacturing**

FDM patent expires 2009, 3D printing popularized

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Polymer AM vs Metal AM

Polymer AM	**Metal AM (+ceramics)**
Ambient	Vacuum or inert gas
Low cost equipment	Expensive equipment
Filament, pellets ,	Wires, powders
Low energy	High energy,
Lower temperature	High temp
Less slow	Slow

Both

Near netshape = low waste

Customizable (CAD-based)

Complex geometries

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Polymer Matrix Composite AM

- Carbon fiber or glass fiber reinforced thermoplastic filaments

https://www.youtube.com/watch?v=_7cA23Orioo

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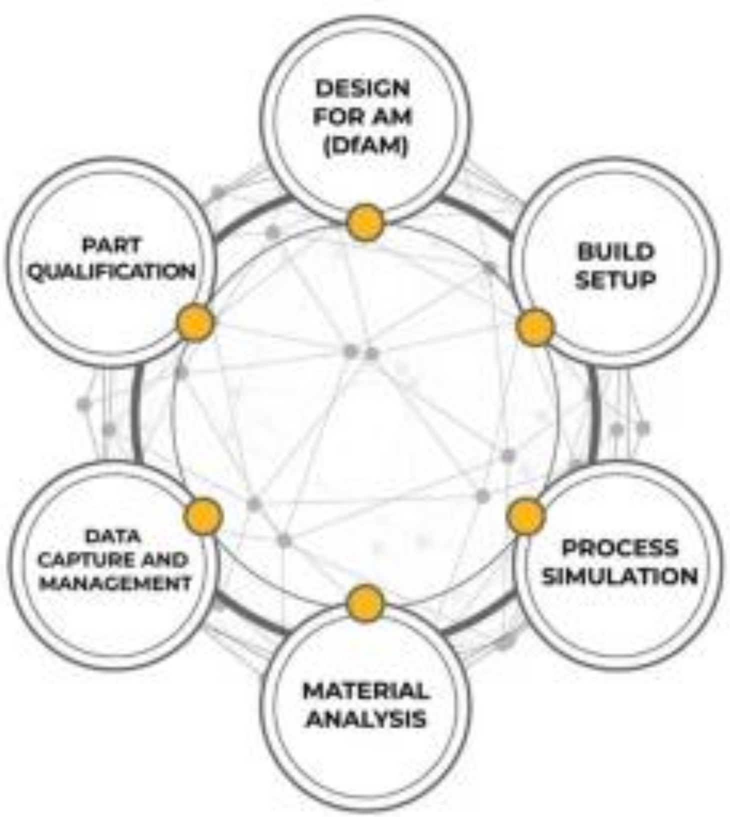
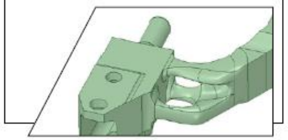
There are many things to consider in industrial AM applications:



Software tools:

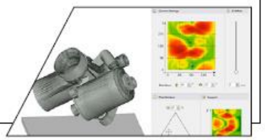
/ Design for AM (DfAM)

- CAD Modeling
- Topology Optimization
- Lattice and Light weighting



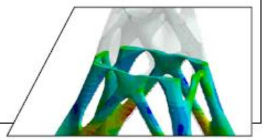
/ Build Setup

- STL File Repair and Geometry Manipulation
- Part Nesting and Support Generation
- Orientation Guidance and Wizards



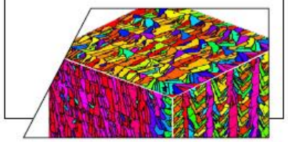
/ Process Simulation

- Metal AM Process Simulations
- Distortion Compensation
- Build Failure Prediction



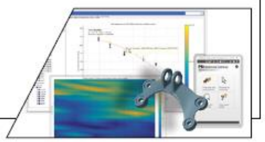
/ Material Analysis

- Curated Material Property Databases
- Grain Morphology Predictions
- Melt pool and Porosity Prediction



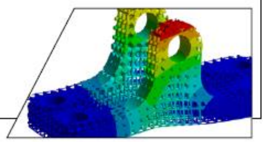
/ Data Acquisition and Management

- Traceability and full control of AM Data
- Consolidate, control and share AM data across organization



/ Part Qualification

- Design Validation
- Structural and Thermal Analysis
- Document control and Certification



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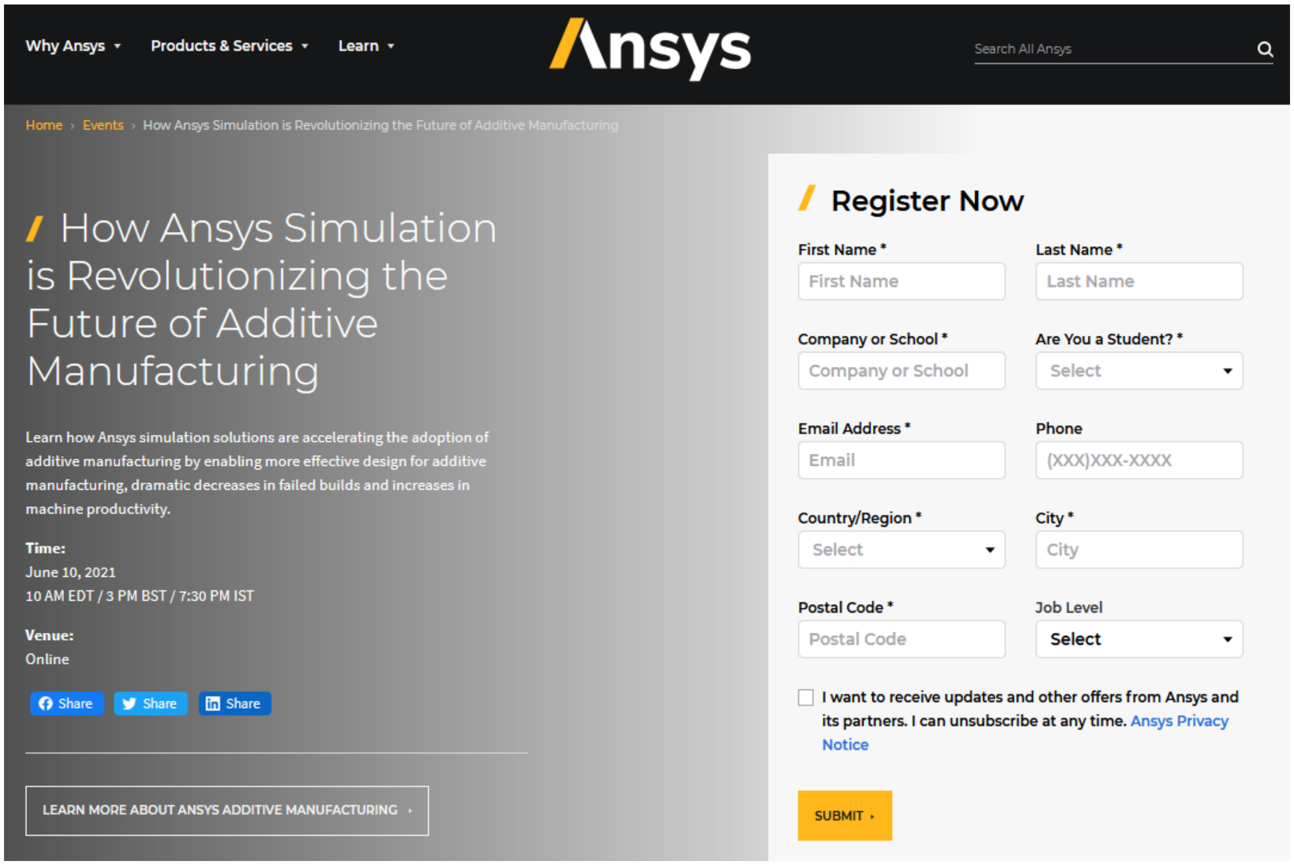
Additive manufacturing and Simulation



www.ansys.com/events/how-ansys-simulation-revolutionizing-future-additive-manufacturing

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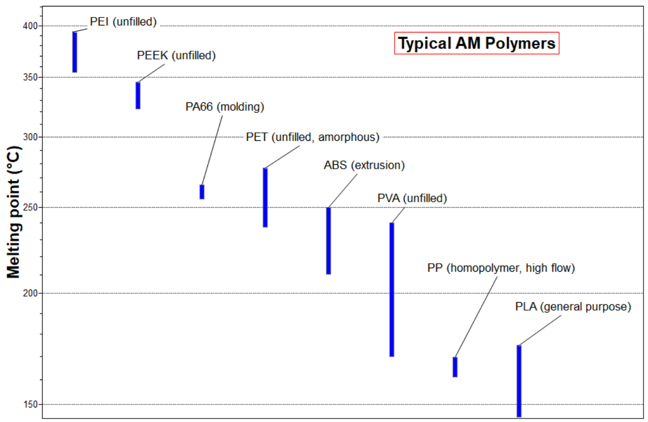
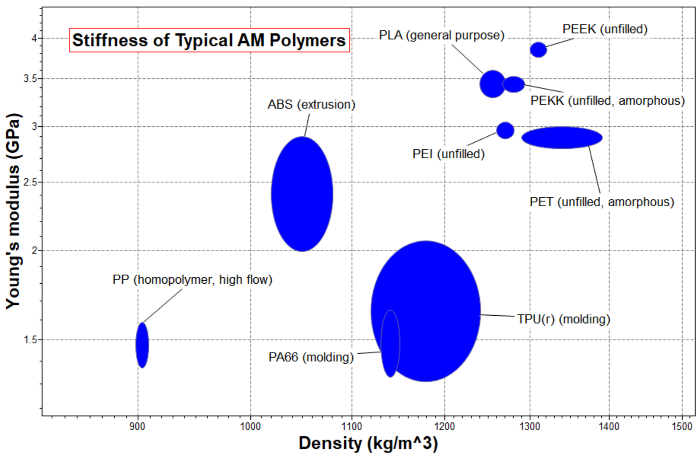
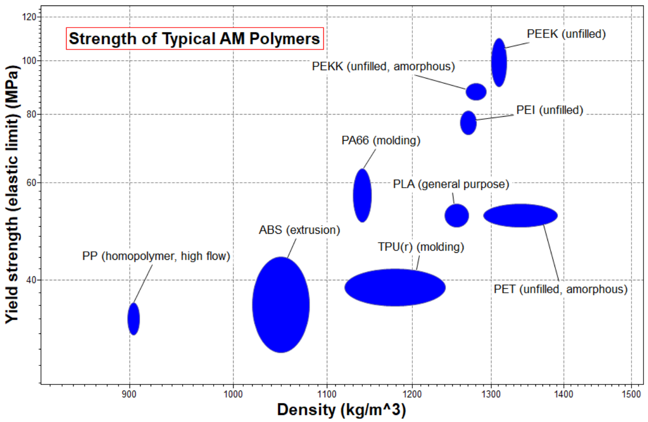
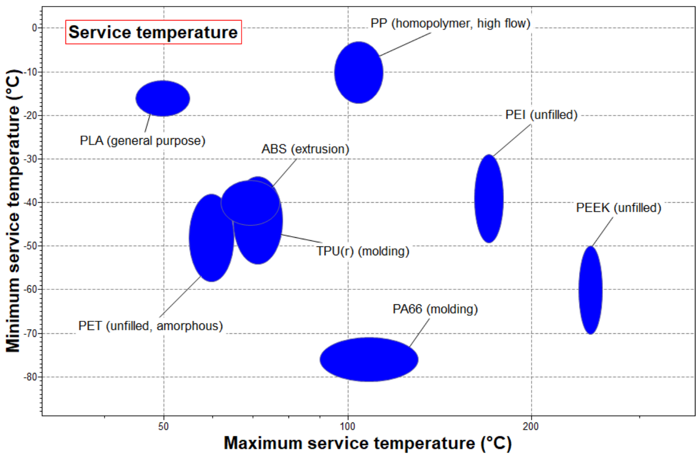
Software – examples and case studies









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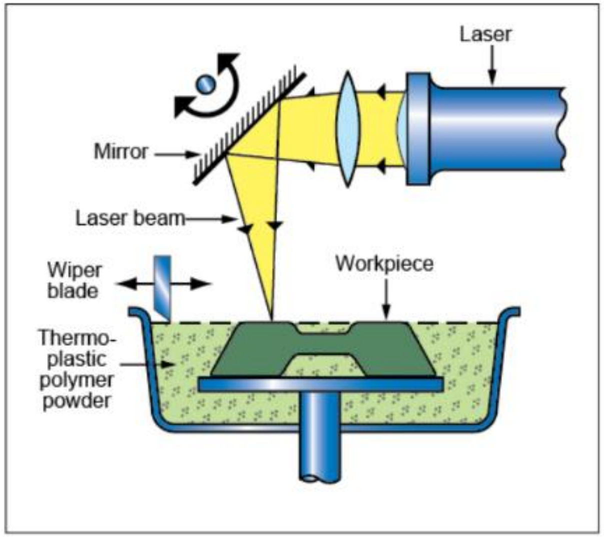
Are materials made by polymer AM any good?

Additive Manufacture (AM) or ***3D printing*** is seen as part of the ongoing "4th Industrial Revolution" (following the revolutions of steam, electricity and information technology). AM technologies use computer-controlled deposition to build shapes layer-by-layer. All can create shapes of great complexity without the need for dies or molds. But is the material made in this way as good as that made by conventional methods such as injection molding?



Selective Laser Sintering (polymers)

- Which polymers can be shaped by AM?
- Explore the properties of conventional Acrylonitrile butadiene styrene (ABS), for which there is a record in the MS&E DB, by making a chart with Tensile Strength (MPa) on the y-axis and Elongation (%) on the x-axis

AM method	Tensile strength (MPa)	Elongation (%)
PLATCure ABS1	50 - 54	4 - 8
ABfled ABS2	26 - 30	12 - 15
Accura ABS3	40 - 44	10 - 14
DWS Systems ABS4	34 - 37	7 - 10

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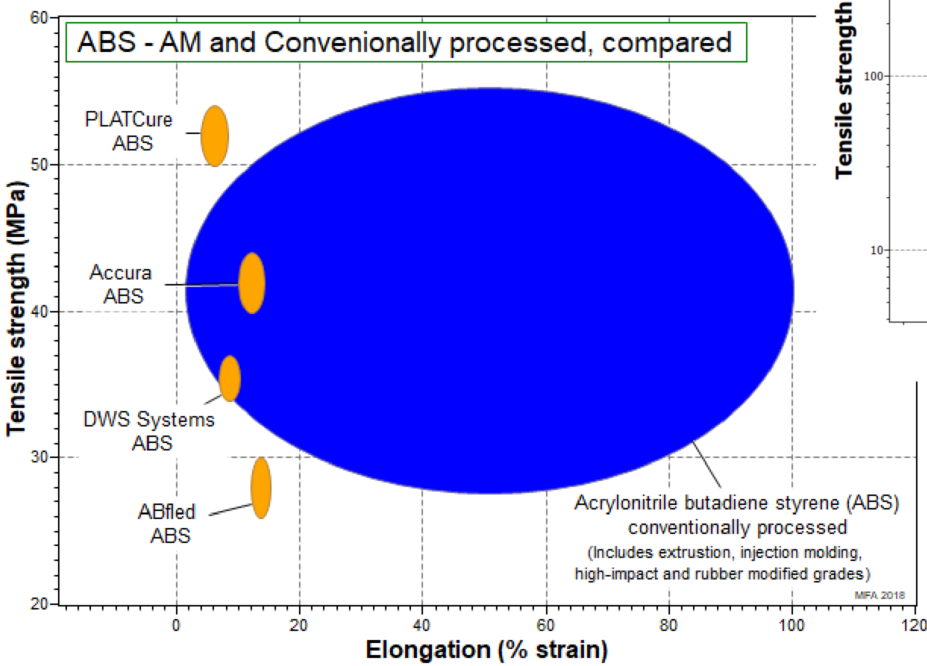
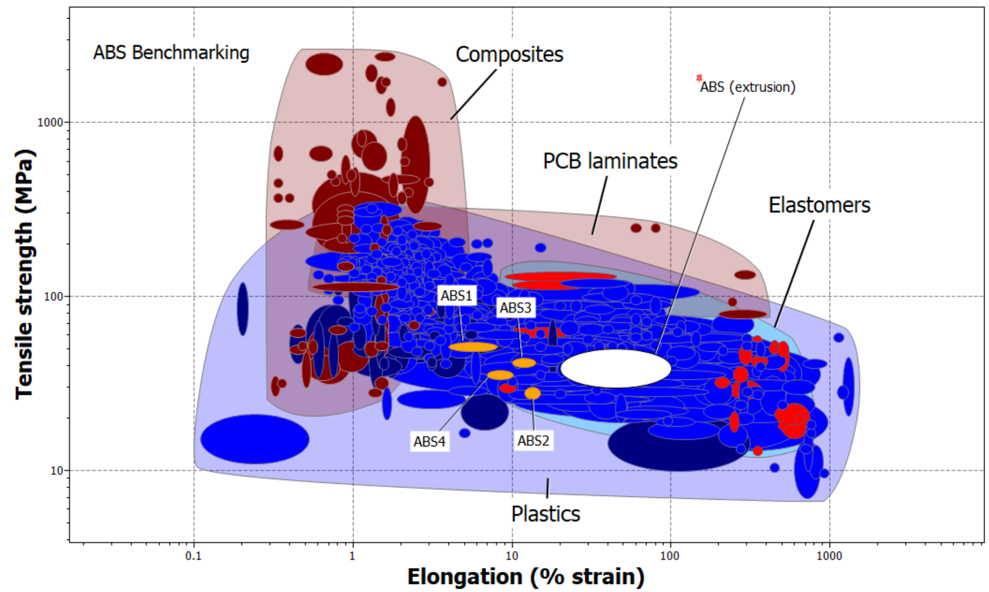
Are materials made by polymer AM any good?

Micro-project 1





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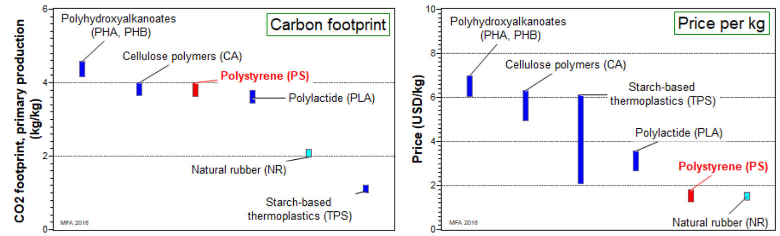
Is PLA really greener than oil-based plastics?

Micro-project 2



- What is PLA? (Use the Search facility to find the record for PLA. You can copy text and images from the record. To do so, open the record, right-click and copy – the entire record is copied – then paste into WORD – the whole record appears. Select and copy the bits you want to paste into a report.)
- What is PLA made from if it isn't oil? (Explore the record to find out.)
- What is PLA used for? (Explore the record to find out.)
- Are there other commercial biopolymers? (Use the Search facility to find records containing the word Biopolymer.)
- Plot CO2

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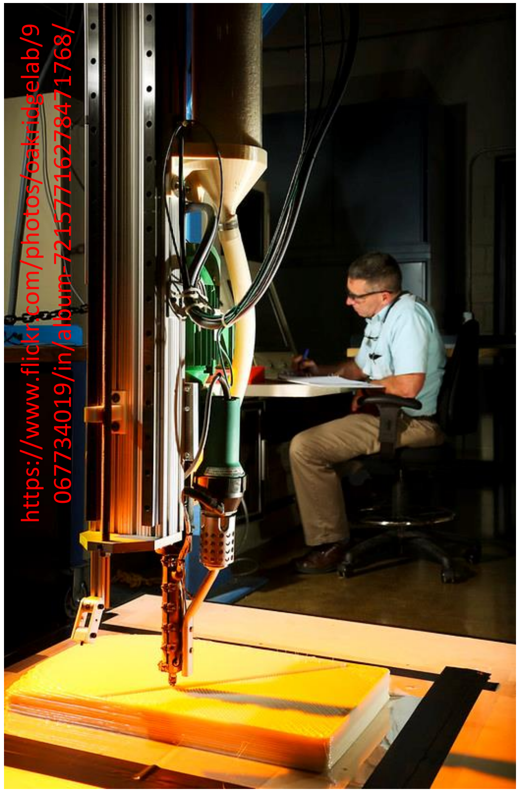
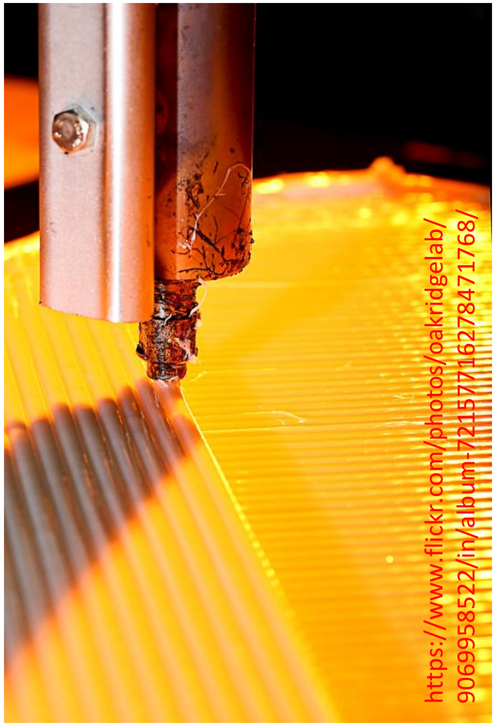
Applications from Oak Ridge National Lab





Source: U.S. Department of Energy, Oak Ridge National Laboratory CC BY 2.0

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Applications in the future?

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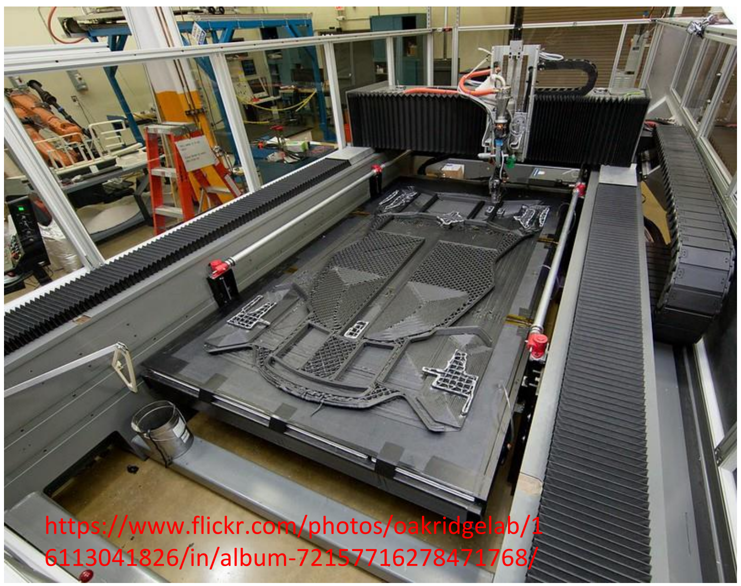
Large Scale Additive Manufacturing



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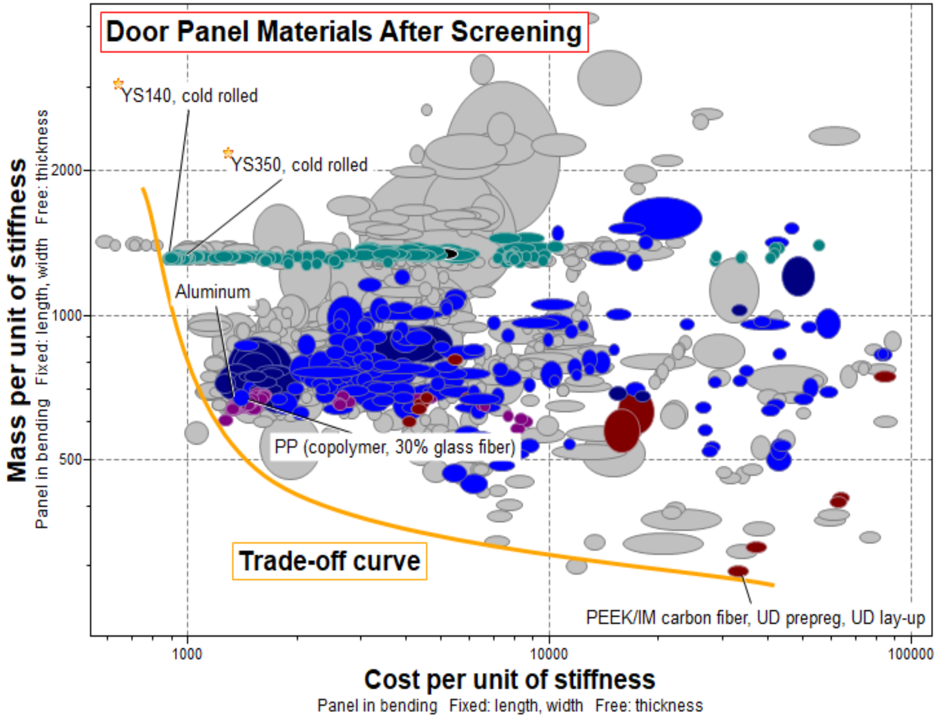
Reality check – the Senvol Database

Q: Can automotive door panels be produced by additive manufacturing?



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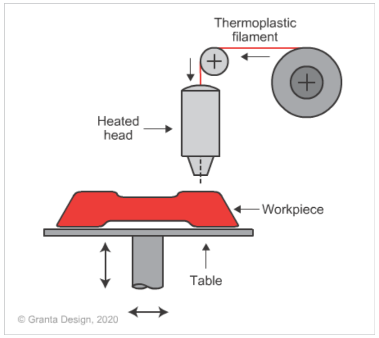
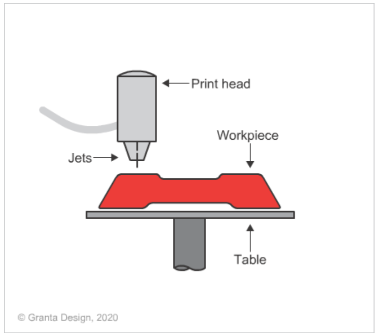
Additive Manufacturing Technologies for polymers

https://grantadesign.com/education/teachingresources/ongoing-development/additive-manufacturing/

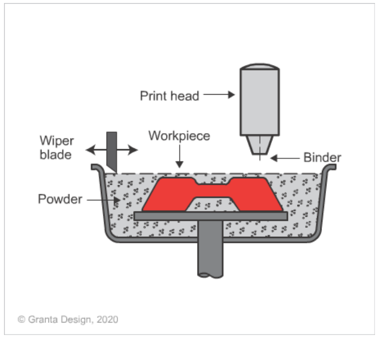
Material extrusion



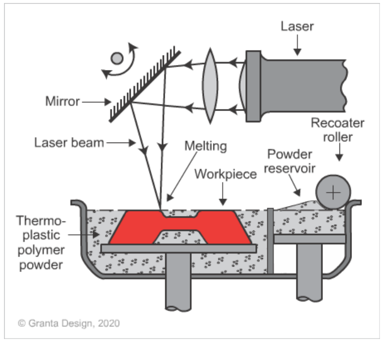
Material jetting



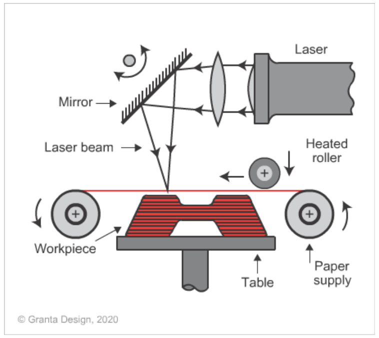
Binder jetting



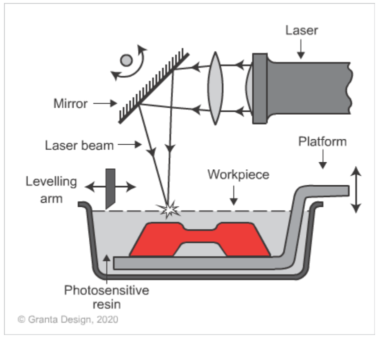
Powder bed fusion



Sheet lamination



Vat photopolymerization



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Questions on the library: Deposition methods

1.1 Why are this category called deposition methods?

1.2 Are there any disadvantage for complex geometries?

1.3 Can polymers as well as metals be used to build objects?

1.4 What is the difference between this category and 3D printing

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Questions on the library: Vat Photopolymerization

5.1 What type of materials are used for photolithography?

5.2 What kind of light is used to cure the resin?

5.3 How can build “overhangs” be achieved in this method?

5.4 How can light degradation of the final product be avoided?

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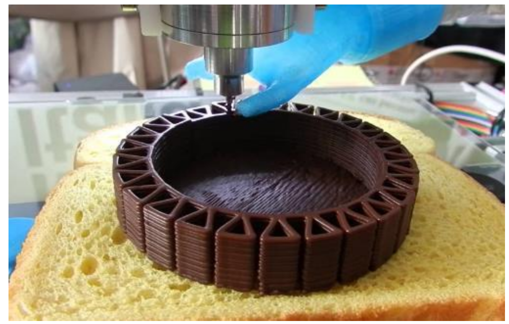
Additive Manufacturing across different sectors

Construction

Source: m-tec (2020)

Food

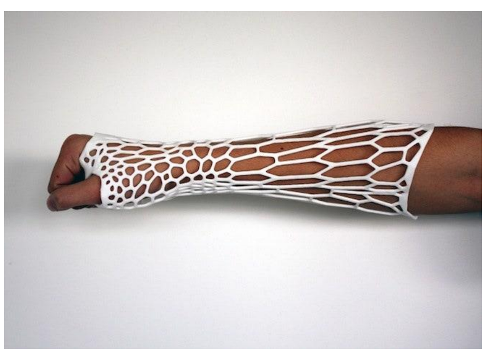


Source: Fabbaloo (2018)

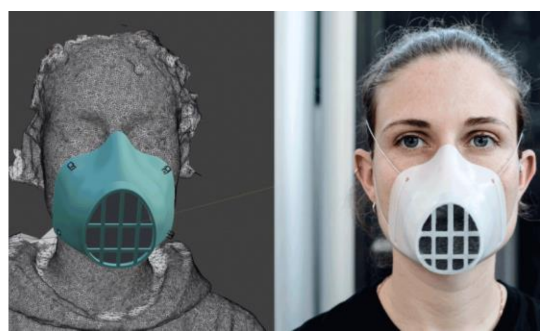
Aerospace/Automotive

Source: AMFG.ai (2019)

Health & Biomedical



Source: Pixabay (2020)



Source: 3D Printing Media Network (2020)

Source: Shutterstock (2020)

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Any Questions?

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Assessment

- Multiple choice questions
  - 7 questions (Based on the lecture content, learning outcomes and learning resources)
- Assessment via **Teams** and **Forms** platforms
  - Camera will need to be turned on
  - Duration - 7 minutes total (approx. 1 min per question) (***Forms records the duration for each participant***)
  - External invigilator on the day from the lead partner – EWF
  - Results (within one week of the assessment)
  - Score at least 60% to pass (to receive SAM's certificate)
  - If lower, you get another opportunity with another new assessment (new date TBC)
  - SAM Certificate to be issued within 1 month.

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