Semnan University
Additive Manufacturing Laboratory (AML)

آزمایشگاه تحقیقاتی
ساخت افزایشی
دانشگاه سمنان

مباحث منتخب (ساخت افزایشی)

عملیات ثانویه (Post-processing)

استاد درس:

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Post-Processing

Which kinds of post-processing methods are you familiar with?

Post-Processing

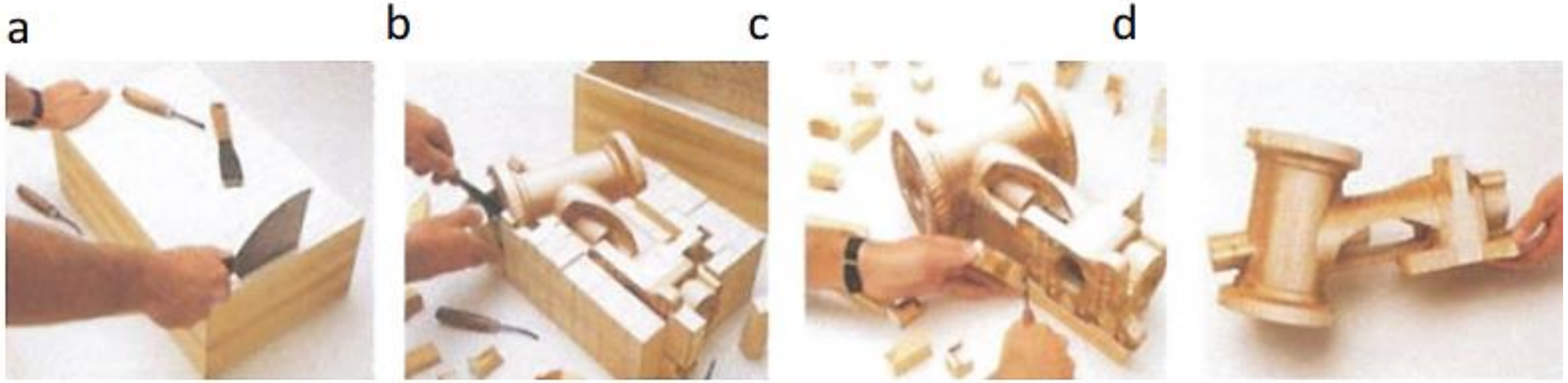
- Reasons for post-processing: **form, fit, and/or function**
- Post-processing techniques used **to enhance components** or **overcome AM limitations**:
  - Improving surface quality
    - Support material removal
    - Surface texture improvement
    - Aesthetic improvement
  - Improving dimensional deviations
  - Improving mechanical properties
    - Property enhancement using **nonthermal** techniques
    - Property enhancement using **thermal** techniques

Post-Processing: Improving surface quality

- Support material removal (the most common type of post-processing):
  1. **Natural** supports
  2. **Synthetic** supports

Post-Processing: Improving surface quality

- Natural support removing
  - The part being built is **fully encapsulated** in the build material
  - **Powder Bed Fusion** (PBF) and **Binder Jetting** (BJ)
  - **Bond-then-form** sheet metal lamination processes



(a) The laminated stack is removed from the machine's elevator plate.
(b) The surrounding wall is lifted off the object to expose cubes of excess material.
(c) Cubes are easily separated from the object's surface.
(d) The object's surface can then be sanded, polished or painted, as desired.

Fig. 16.2 LOM support removal process (de-cubing) process, showing (**a**) the finished block of material; (**b**) removal of cubes far from the part; (**c**) removal of cubes directly adjacent to the part; (**d**) the finished product. (Photo courtesy of Worldwide Guide to Rapid Prototyping website (C) Copyright Castle Island Co., All rights reserved. Photo provided by Cubic Technologies)

Post-Processing: Improving surface quality

- Natural support removing
- In **polymer PBF** processes, it is typically necessary to **cool down** the built part (as embedded inside the powder to minimize part **distortion** due to **non-uniform cooling**).
- **Brushes**, **compressed air**, and **light bead blasting** are commonly used to remove loosely adhered powder.
- **Woodworking tools** and **dental cleaning tools** are commonly used to remove **powders which have sintered** to the surface or **powder entrapped in small channels or features**.

Fig. 12.6 Powder bed fusion parts being removed from the powder 'cake'

Post-Processing: Improving surface quality

- Natural support removing
- Automated loose powder removal processes

Fig. 16.1 Automated powder removal using vibratory and vacuum assist in a Z Corp 450 machine. (Photo courtesy of Z Corporation)

Post-Processing: Improving surface quality

- Synthetic support removing
- Supports for **overhanging** features
- In PBF techniques for metals, synthetic supports are also required to **resist distortion**.
- Synthetic support's material: 1- **build material** or 2- **secondary material**
- Secondary support materials simplifies support removal because they are either **weaker, soluble in a liquid solution**, or to **melt at a lower temperature** than the build material.

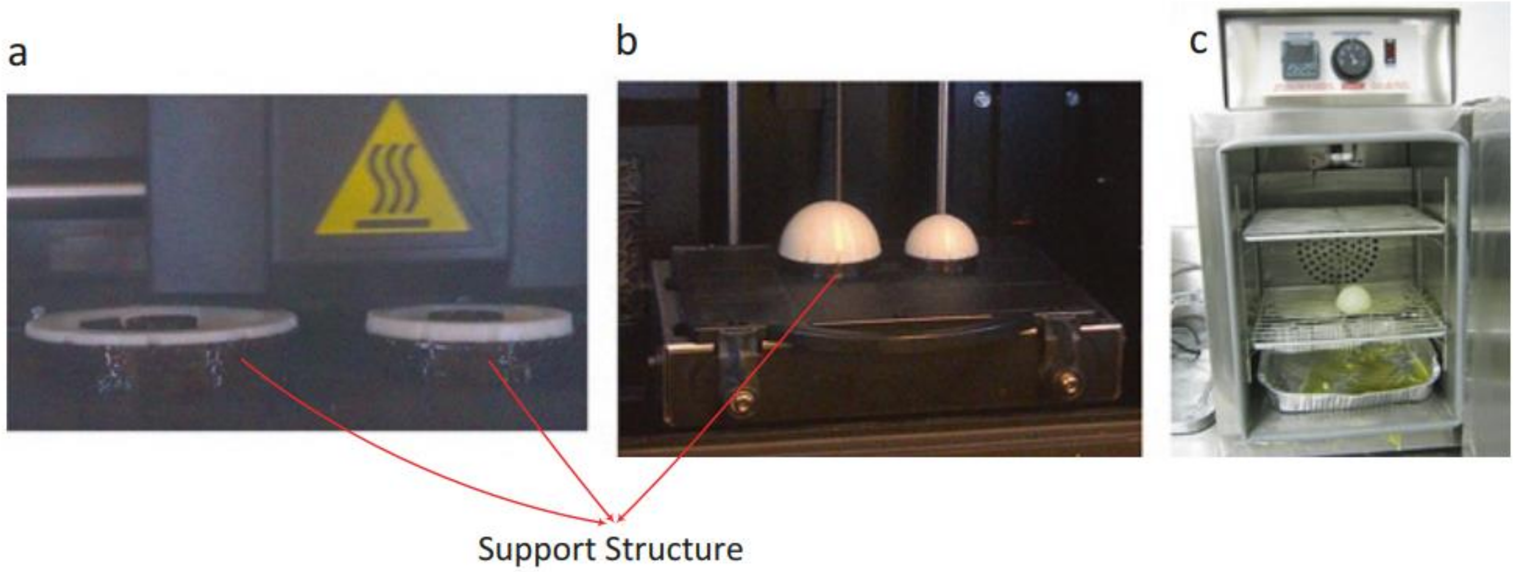


Fig. 16.3 (**a**) and (**b**) secondary support structures are used to support the part (**c**) an oven provides thermal support removal

Post-Processing: Improving surface quality

- Supports made from the build material
- All **Material Extrusion**, **Material Jetting**, and **Vat Photopolymerization** processes require supports for **overhanging** structures and to **connect the part to the build platform**.
- The **downward-facing features** may require subsequent **sanding** and **polishing** due to witness marks of the supports.

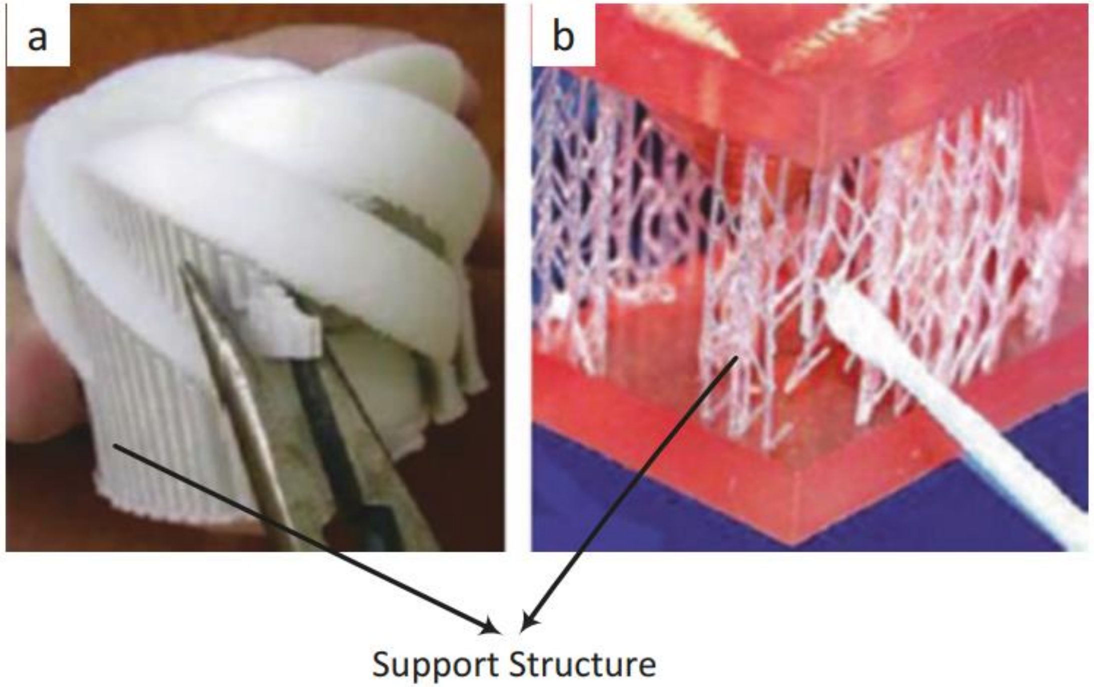


Fig. 16.4 Breakaway support removal for (**a**) an MEX part. (Photo courtesy of Jim Flowers) and (**b**) an SLA part. (Photo courtesy of Worldwide Guide to Rapid Prototyping website. Copyright Castle Island Co., All rights reserved. Photo provided by Cadem A.S., Turkey)

Post-Processing: Improving surface quality

- Supports made from the build material
- **PBF** and **Directed Energy Deposition** (DED) processes for **metals** and **ceramics** also typically require support materials.
- For these processes the **metal supports are often too strong** to be removed by hand; thus, the use of **milling**, **band saws**, **cutoff blades**, **wire EDM**, or **pneumatically driven chisels** can be used for removing support structures.

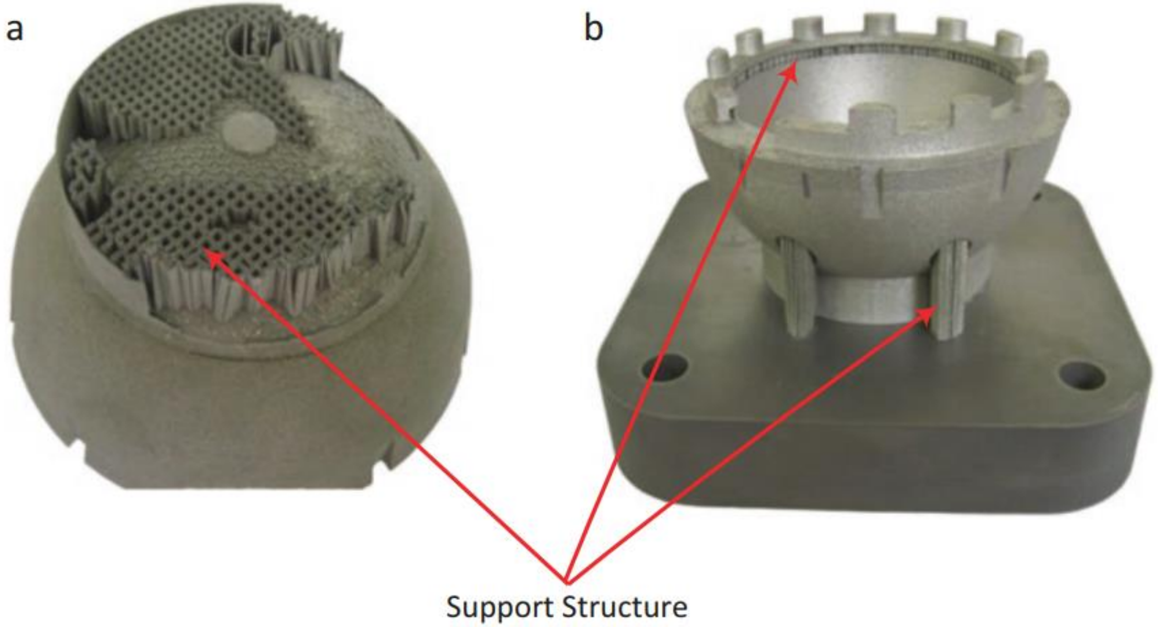
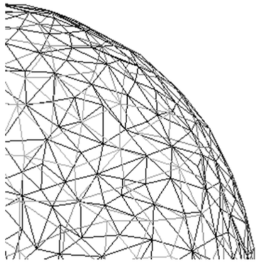


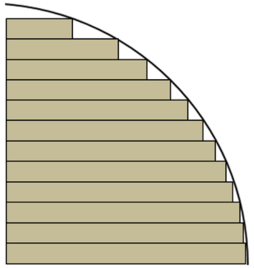
Fig. 16.5 (**a**, **b**) Laser-Based Powder Bed Fusion (LB-PBF) acetabular cup for a hip replacement surgery, made from Ti-6Al-4 V

Post-Processing: Improving surface quality

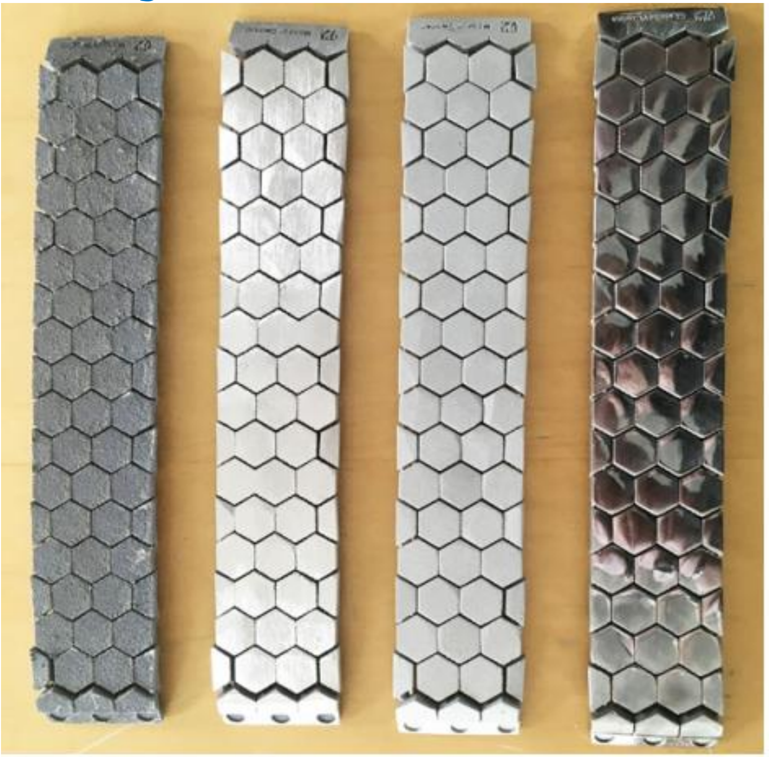
- **Surface Texture Improvements:**
- Common **undesirable surface texture features**:
  - stair-steps
  - powder adhesion
  - fill patterns from MEX or DED systems
  - witness marks from support material removal
- **Powder adhesion** is a fundamental characteristic of:
  - BJ
  - PBF
  - Powder-based DED processes



STL model



Layered model

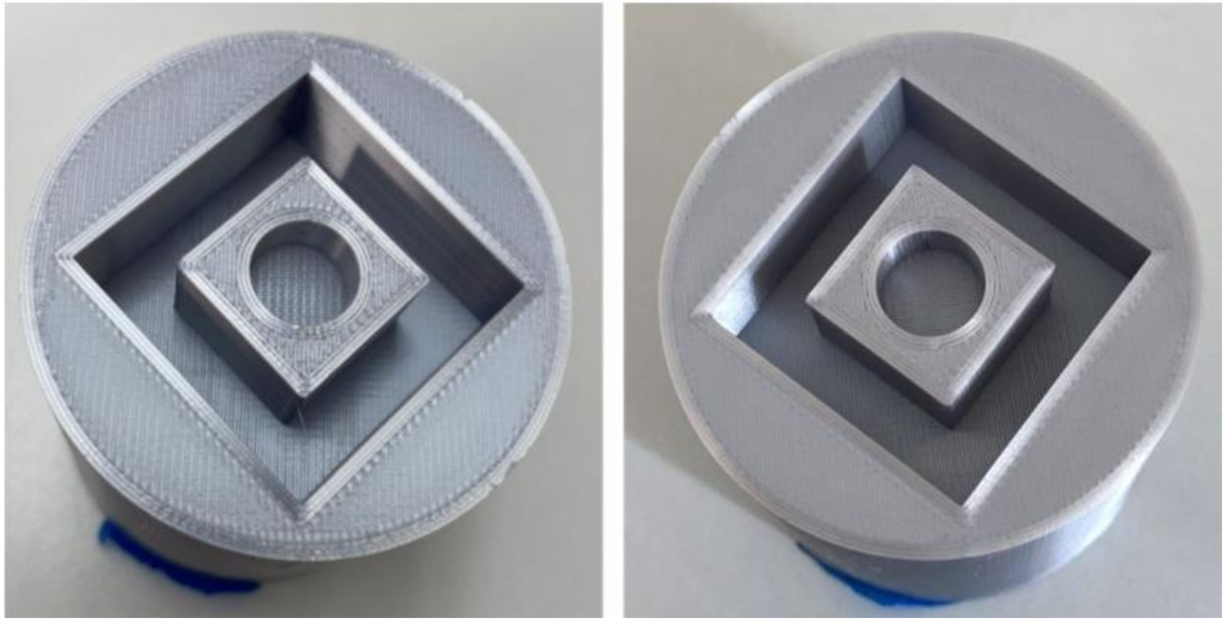


Remove from build platform and remove supports	Linish surface with belt sander	Media-blast with glass beads	Polish
30 minutes	30 minutes	5 minutes	4~5 hours

- For **matte** surface finish: **bead blasting (even the surface texture**, remove **sharp corners from stair-stepping)**
- For **smooth** or **polished finish**: **wet** or **dry sanding** and **hand polishing**

Post-Processing: Improving surface quality

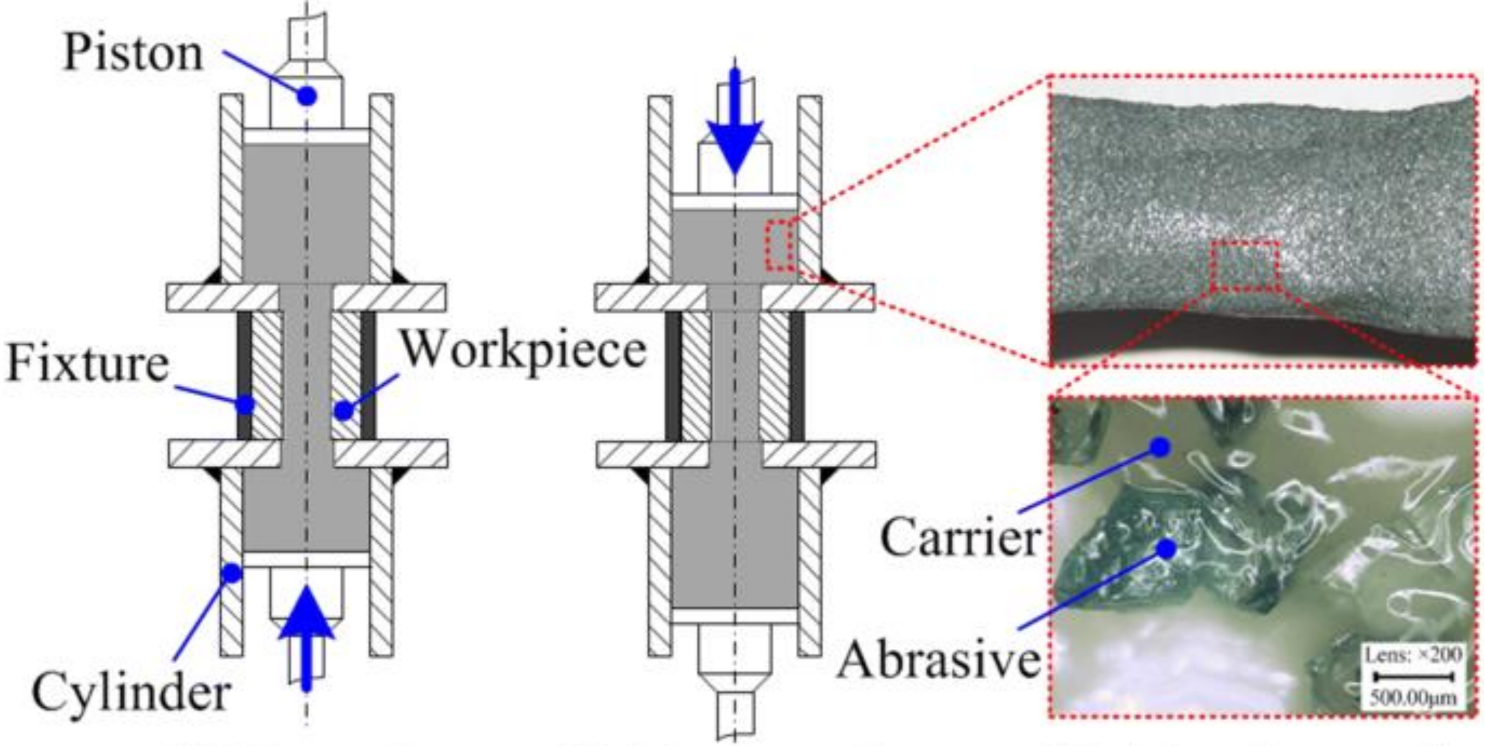
- **Surface Texture Improvements:**
- Paint the surface (e.g., with cyanoacrylate, or a sealant) prior to sanding or polishing.
- Benefits of painting: **sealing porosity**, **smoothing** the **stair-step** effect and making **sanding and polishing easier and more effective**.



Post-Processing: Improving surface quality

- **Surface Texture Improvements:**
- Two of the most commonly utilized automated techniques: **tumbling** for **external** features and **abrasive flow machining** for, primarily, **internal** features.

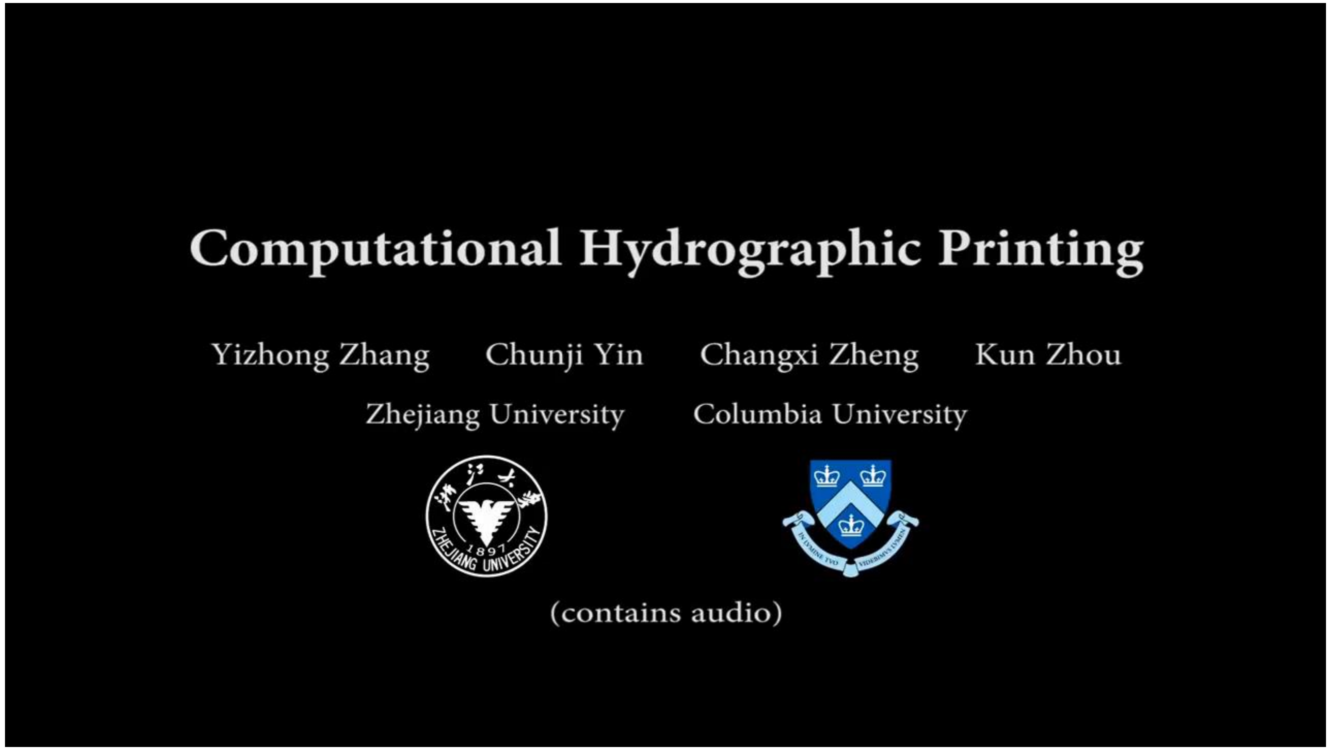
Examples of tumbled AM parts,



(a) Upstroke (b) Downstroke (c) Abrasive media

Post-Processing: Improving surface quality

- **Aesthetic Improvements**
- Surface finish, coloring (dipping, spray, …), electroplating (Cr, Cu, Ni, …)



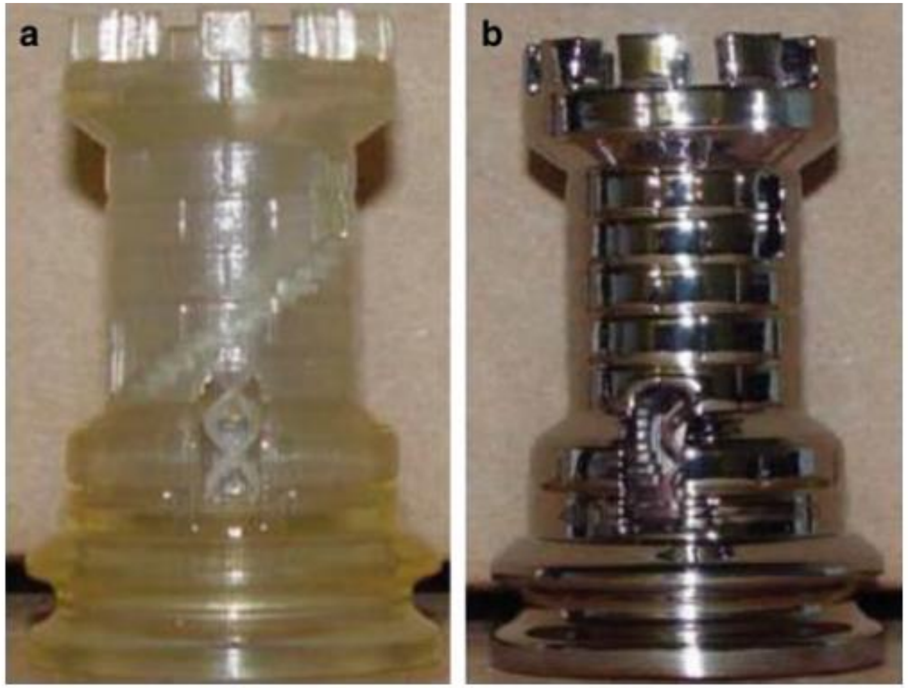


Fig. 16.6 Stereolithography part (**a**) before and (**b**) after chrome plating. (photo courtesy of Artcraft Plating)

Post-Processing: Improving dimensional deviations

- Some processes are capable of **submicron** tolerances, whereas others have deviations above **1 mm**.
- Typically, **the larger the build volume** and **the faster the build speed**, **the worse the accuracy**.
- Sources of inaccuracy:
  - **positioning** and **indexing limitations** of specific machine architectures
  - **lack of closed-loop** process monitoring and control strategies
  - operator skill
  - melt pool or droplet size
  - shrinkage
  - residual stress-induced distortion
  - position of parts on the build plate
  - differential cooling in the build chamber

Post-Processing: Improving dimensional deviations

- **Hybrid AM** (integration of additive plus subtractive processing) can be used for process accuracy improvement.
- **Finite element analysis** and **scaling the CAD model** could be used for **compensating shrinkage** and **residual stresses**.

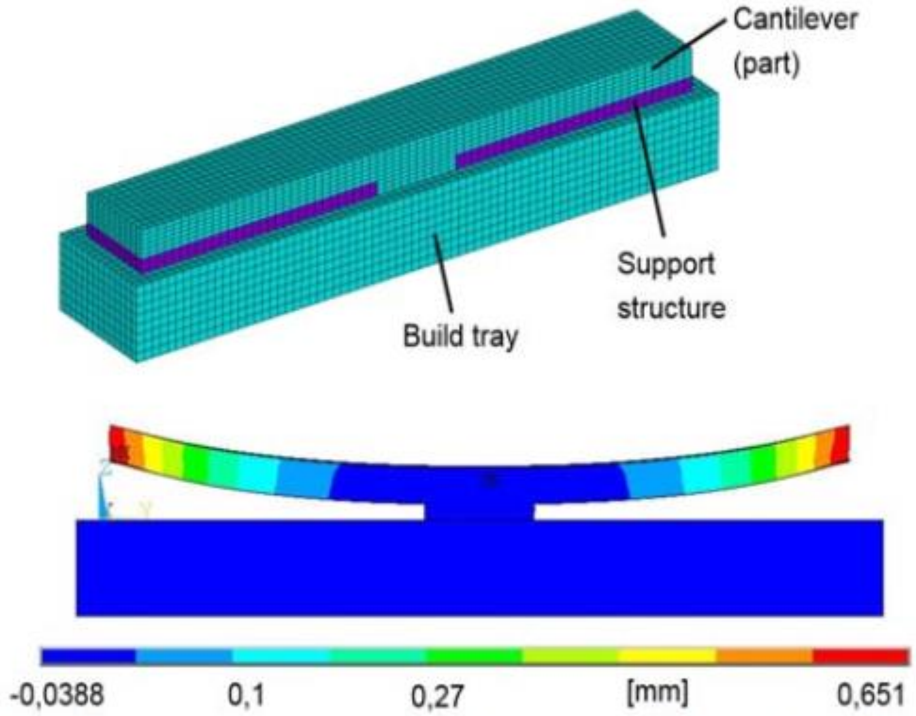


Fig. 2 Simulation result of warpage of a Cantilever (T-structure) after build-up by LBM and the removal of support structures [13].

Post-Processing: Improving dimensional deviations

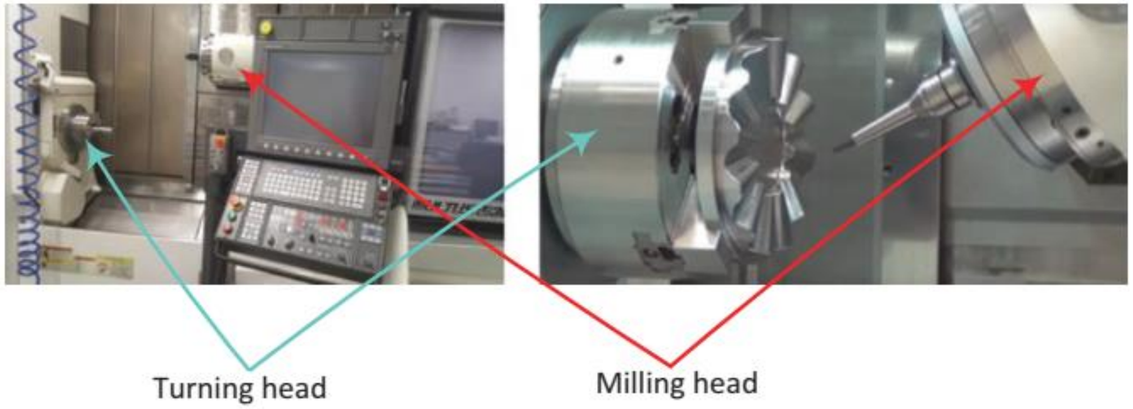


Fig. 16.8 Milling–turning material removal (OKUMA MULTUS U3000). (Photo courtesy of OKUMA)

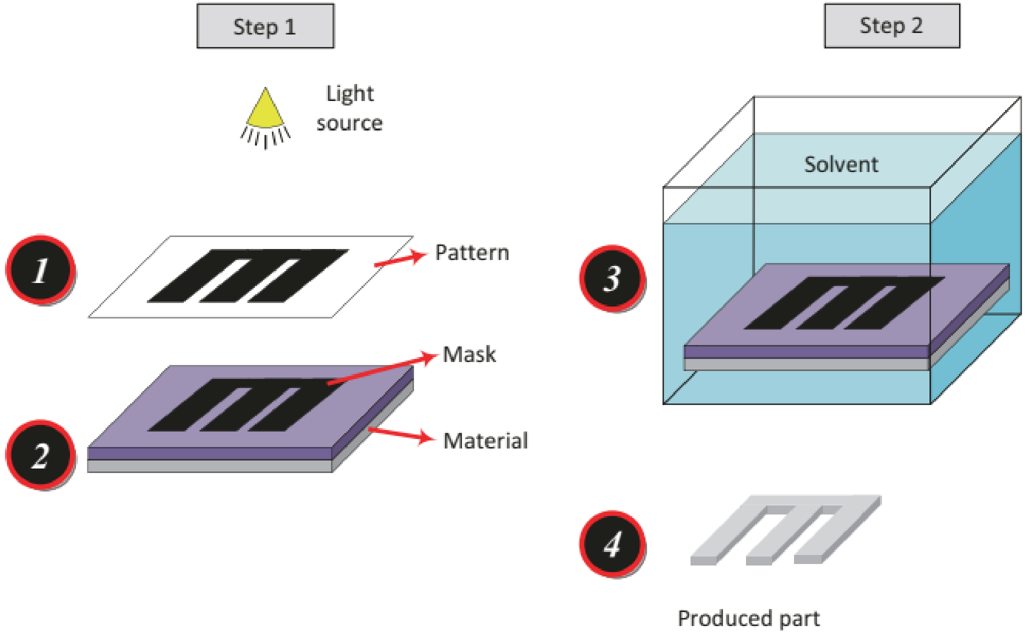


Fig. 16.11 Schematic of photochemical machining

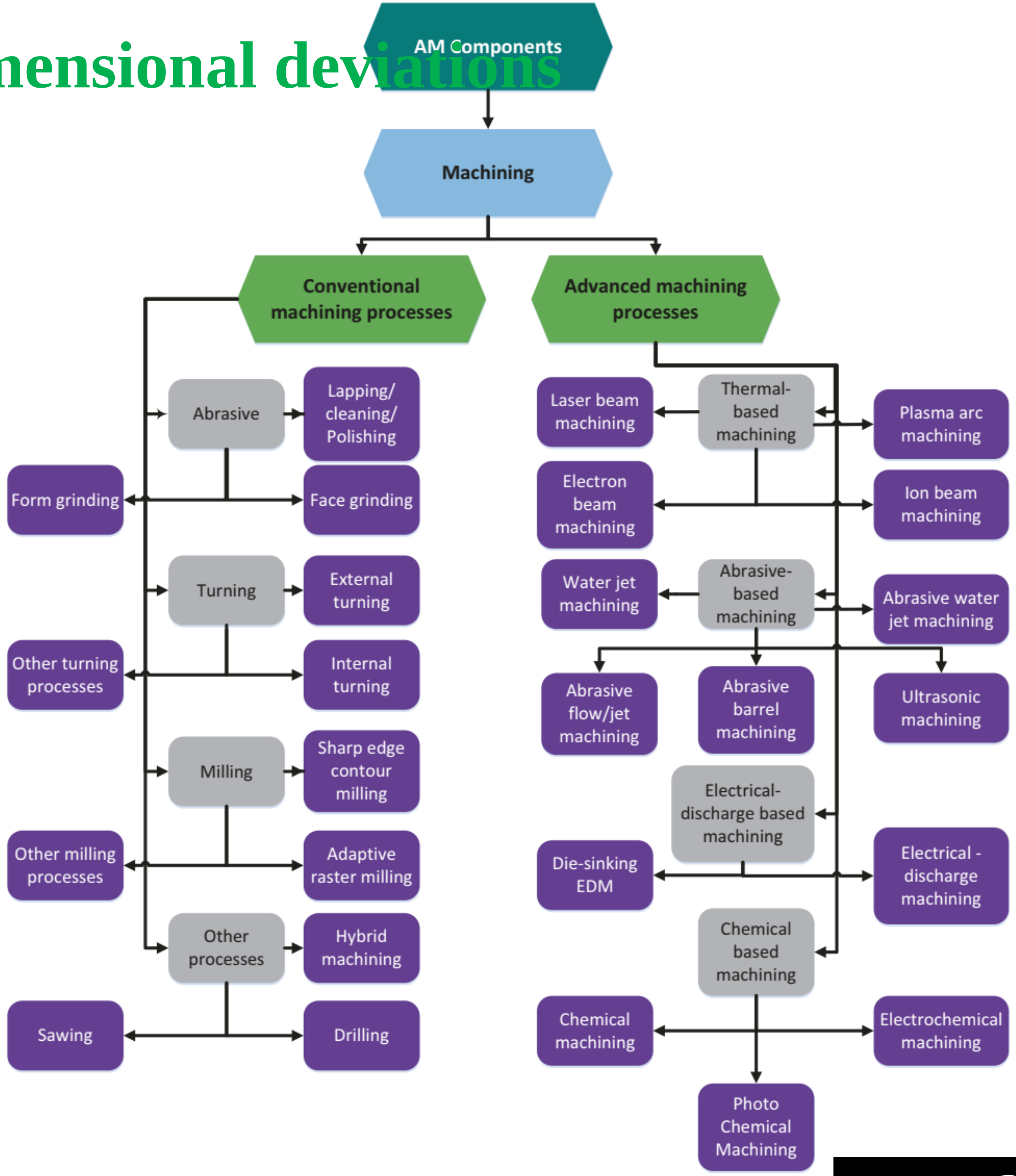


Fig. 16.7 Different machining strategies for AM parts

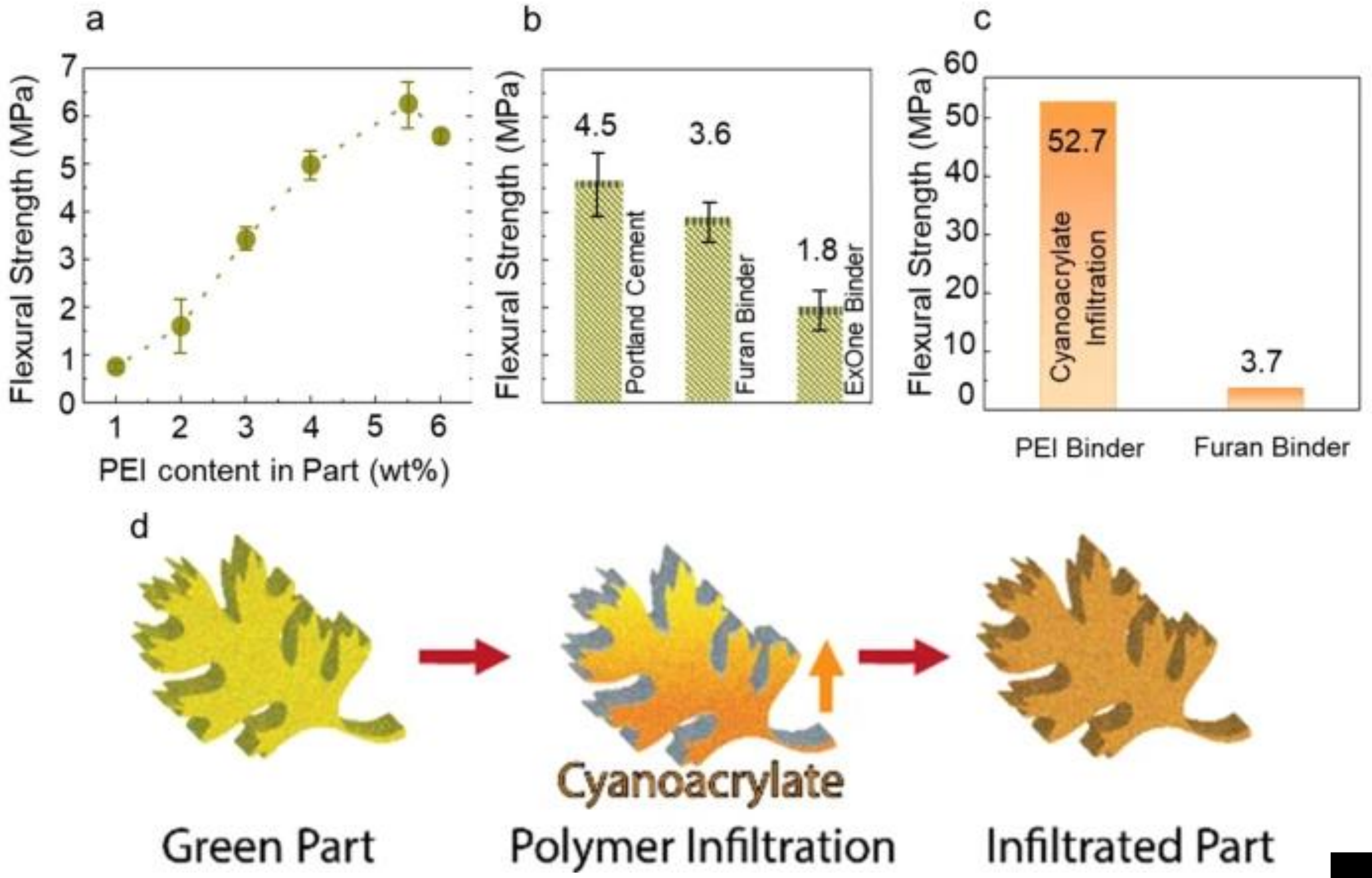
Post-Processing: Improving mechanical properties

- Nonthermal techniques
- **Powder-based** and **extrusion-based** processes often create **porous** structures.
- In many cases, that **porosity** can be **infiltrated** by a higher-strength material, such as **cyanoacrylate** (Super Glue®).
- A common post-processing operation for **photopolymer** materials is **curing** (flooding the part with **UV** and **visible radiation**)
- Placing the part in a **low-temperature oven** (to accelerate and completely cure the photopolymer)

Post-Processing: Improving mechanical properties

- Nonthermal techniques

Fig. 2: Mechanical properties of BJAM as printed and infiltrated parts comparing PEI with traditional binders and other sand composites.



https://www.nature.com/articles/s41467-021-25463-0

Post-Processing: Improving mechanical properties

- Nonthermal techniques
- **Shot peening**: induces (**beneficial**) **residual compressive stress**
- The media is typically steel, ceramic, or glass, but can be any powder with equal or greater hardness than the workpiece.
- 3D printing of gears and turbine blades is a high demand area in AM which require surface treatment like multi-axis shot peening.

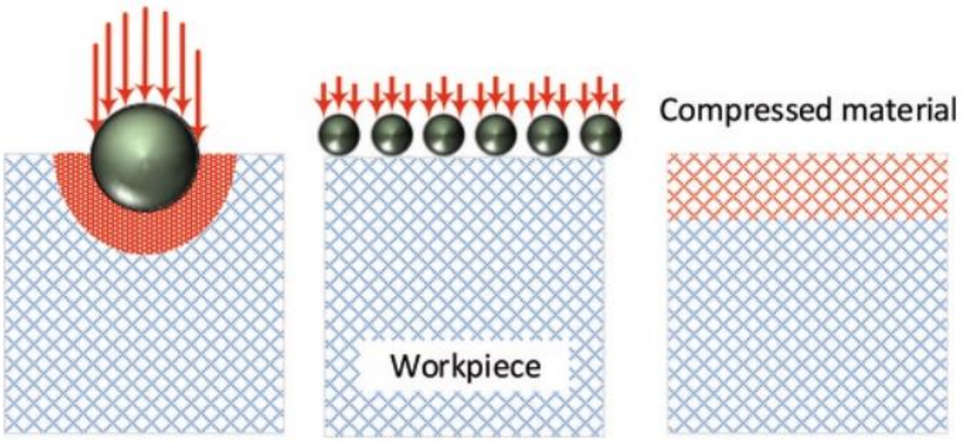
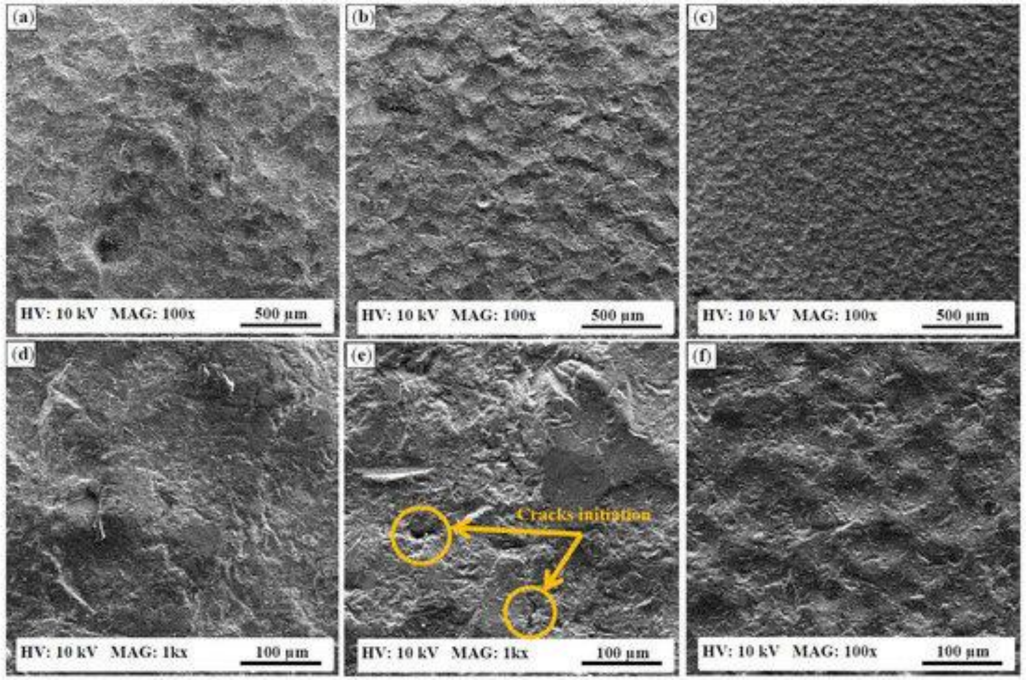


Fig. 16.12 Schematic of shot peening



Post-Processing: Improving mechanical properties

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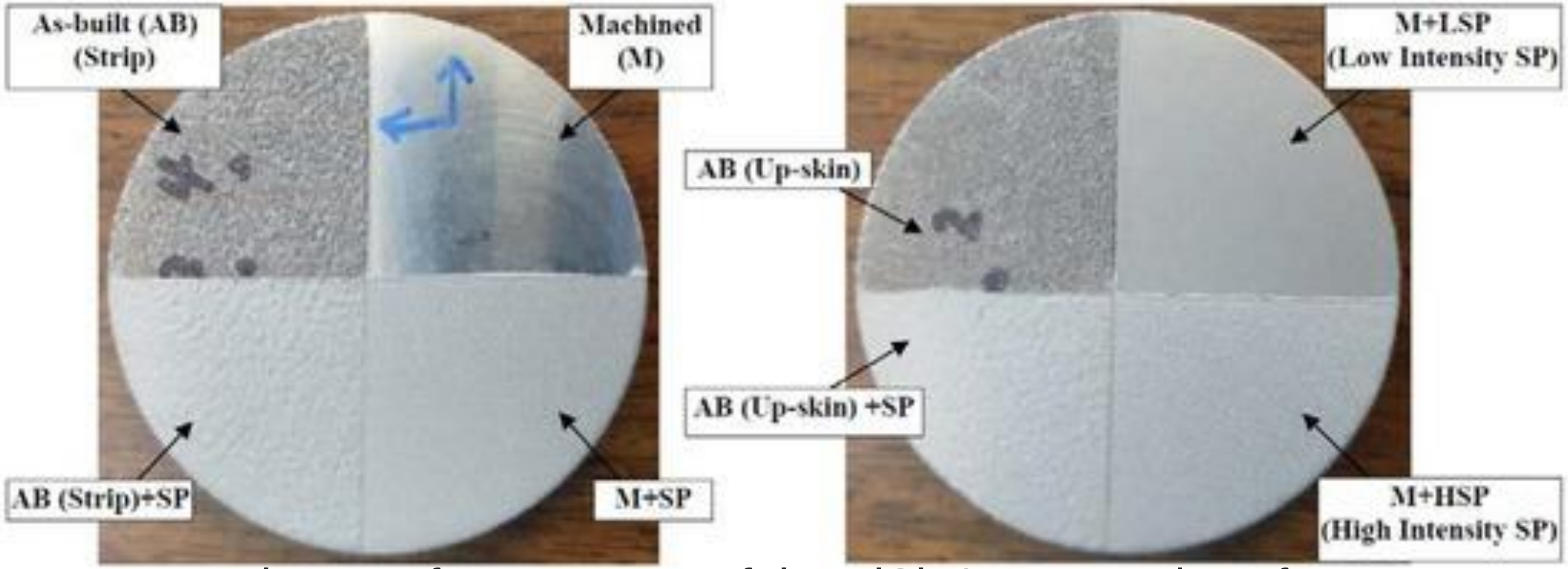


Various surface textures of the AlSi10Mg samples of as-built, rough machined, and shot-peened areas

Post-Processing: Improving mechanical properties

- Nonthermal techniques
- **Cold Isostatic Pressing (CIP)**
- The operational pressure for CIP is 15,000 to 60,000 psi with ambient temperature up to 93 °C.
- Two types of CIP: wet (more uniform) and dry
- CIP is used for consolidation of graphite, polymers, ceramics, and metal AM parts.
- CIP is cheaper than hot isostatic pressing (HIP) although it produces weaker mechanical properties.
- CIP is used before HIP.

Post-Processing: Improving mechanical properties

- Thermal techniques

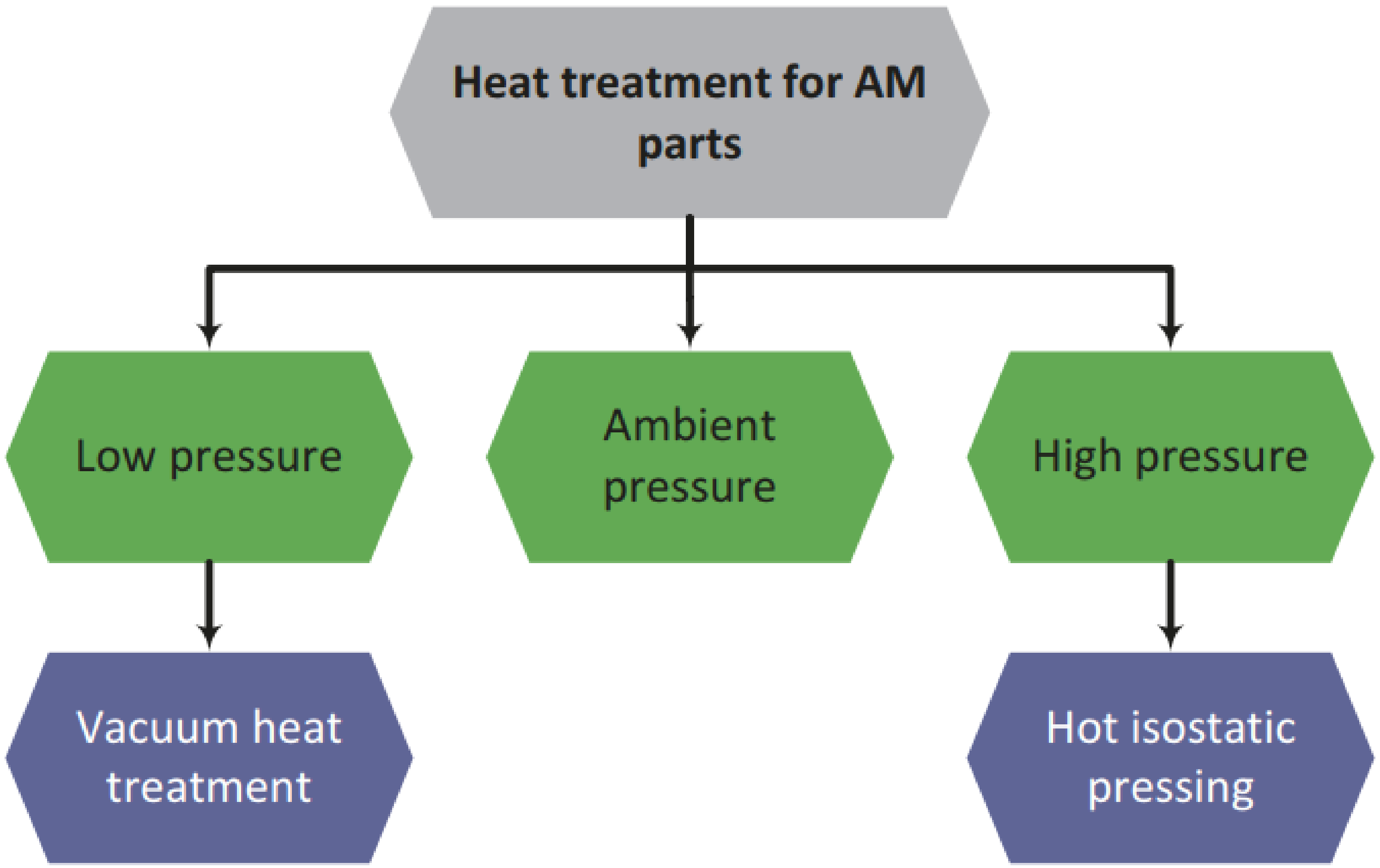
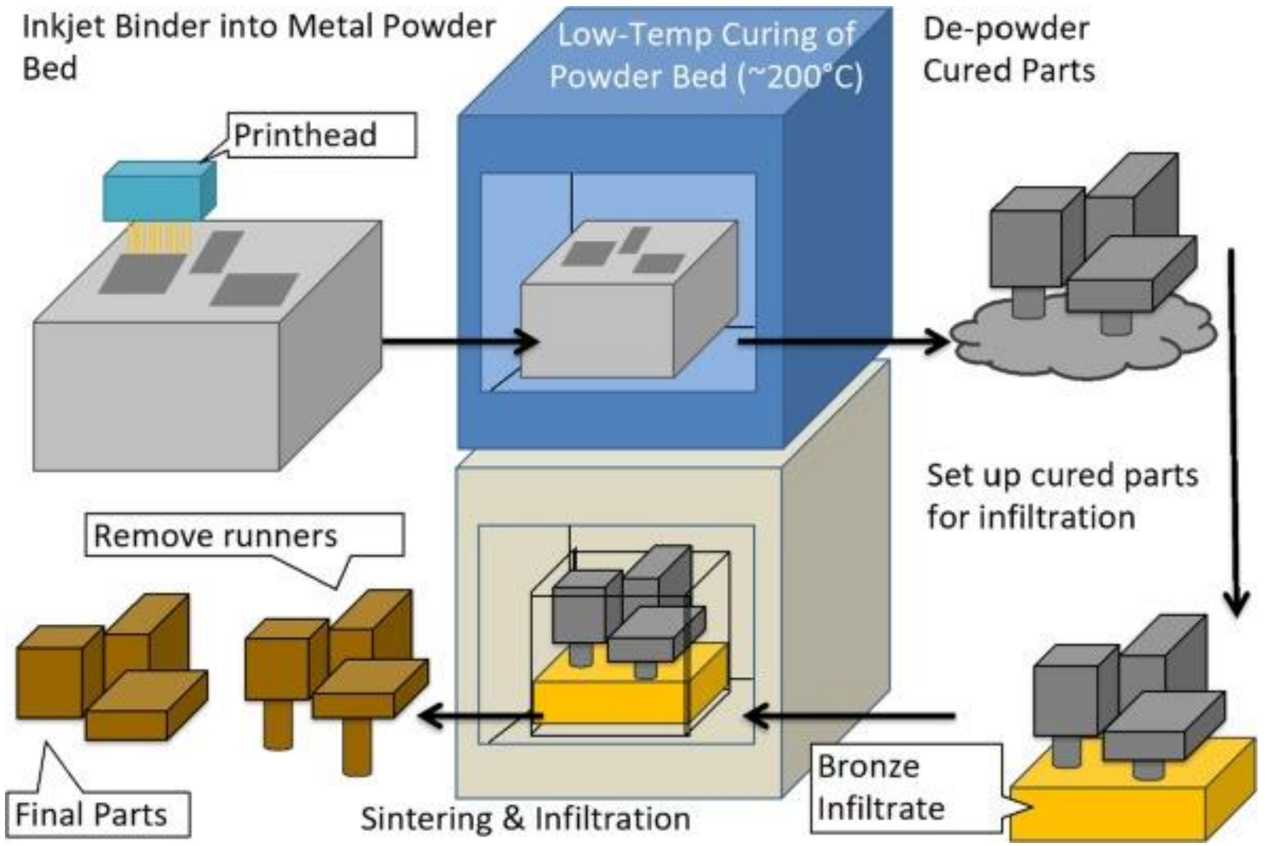


Fig. 16.13 Heat treatment for AM parts based on the operational pressure

Post-Processing: Improving mechanical properties

- Thermal techniques: Ambient Pressure
- In the case of **DED** and **PBF** techniques for metals: **heat treatment** to form the **desired microstructures** and/or to **relieve residual stresses**, **ductility enhancement**
- Thermal treatment for green parts of BJ



Post-Processing: Improving mechanical properties

- Thermal techniques: Low Pressure
- For some AM materials prone to **oxidation**, such as **Ti alloys** and **ceramics**, heat treatment should be performed in a **vacuum** (more expensive compared to that for ambient pressure).
- Vacuum furnaces have uniform temperature in the range of 800–3000 °C with low contamination by carbon, oxygen, and other gases.
- The vacuum pumping system removes low-temperature by-products from the process materials during heating, resulting in a higher purity end product.

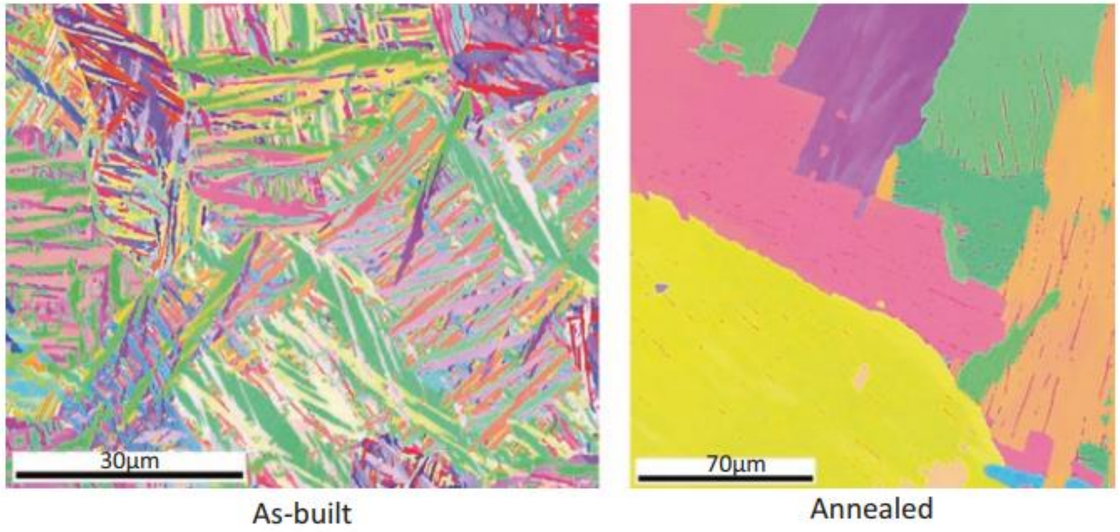
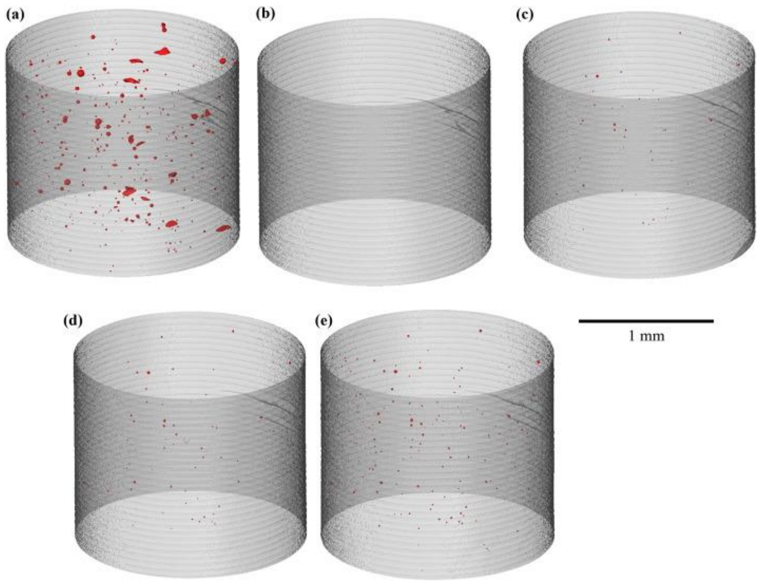
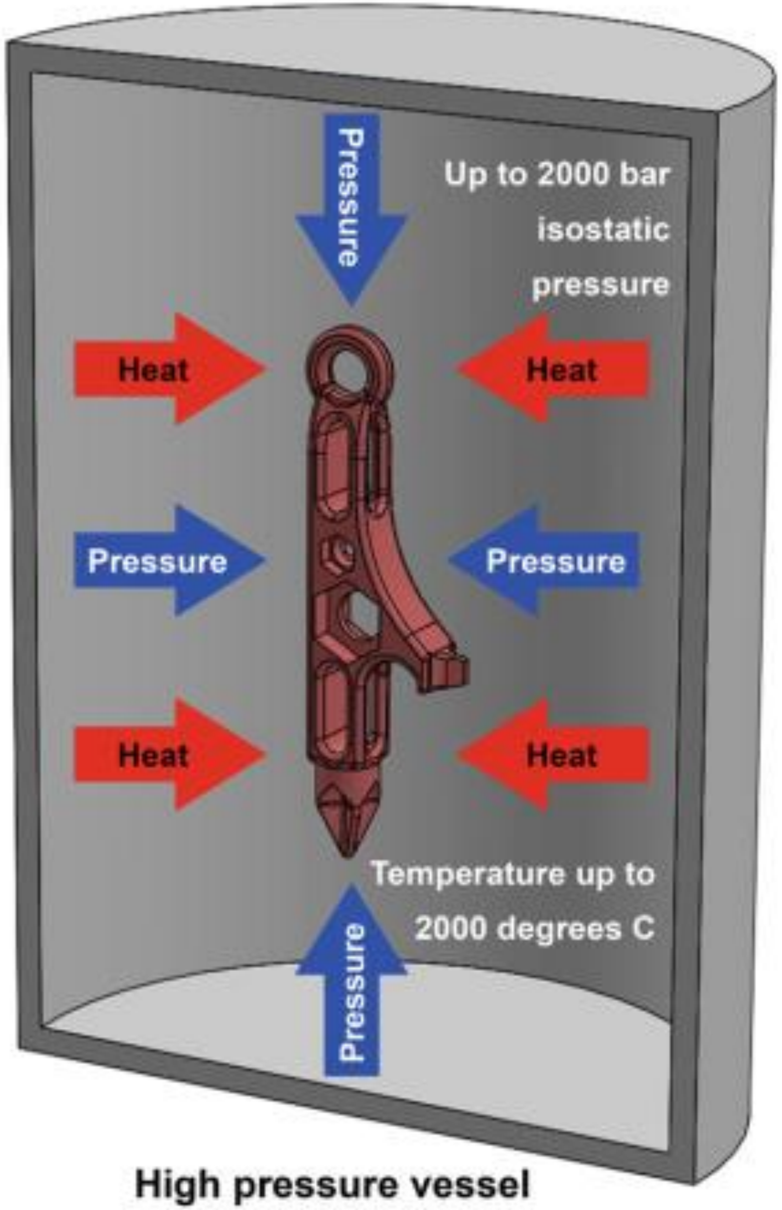


Fig. 16.17 As-built and vacuum annealed Ti-6Al-4V produced by LB-PBF

Post-Processing: Improving mechanical properties

- Thermal techniques: High Pressure (Hot Isostatic Pressing)
- HIP is a **forming** and **densification** process using **heated gas** under **very high pressure**.
- Maximum standard operating pressures range from 1500 to 30,000 psi.
- HIP can significant **reduce porosity** with **little net shape change**.





Post-Processing: Improving mechanical properties

- Thermal techniques: High Pressure (Hot Isostatic Pressing)

- HIPing benefits:
  - Densification of powdered metal parts to nearly 100 percent theoretical density
  - Increased resistance to fatigue and temperature extremes
  - Higher resistant to impact wear and abrasion
  - Improved ductility
  - Little or no secondary machining or manual rework and decreased scrap rate
- HIP can be used to treat **metals**, **ceramics**, **composites**, and **polymer** parts.

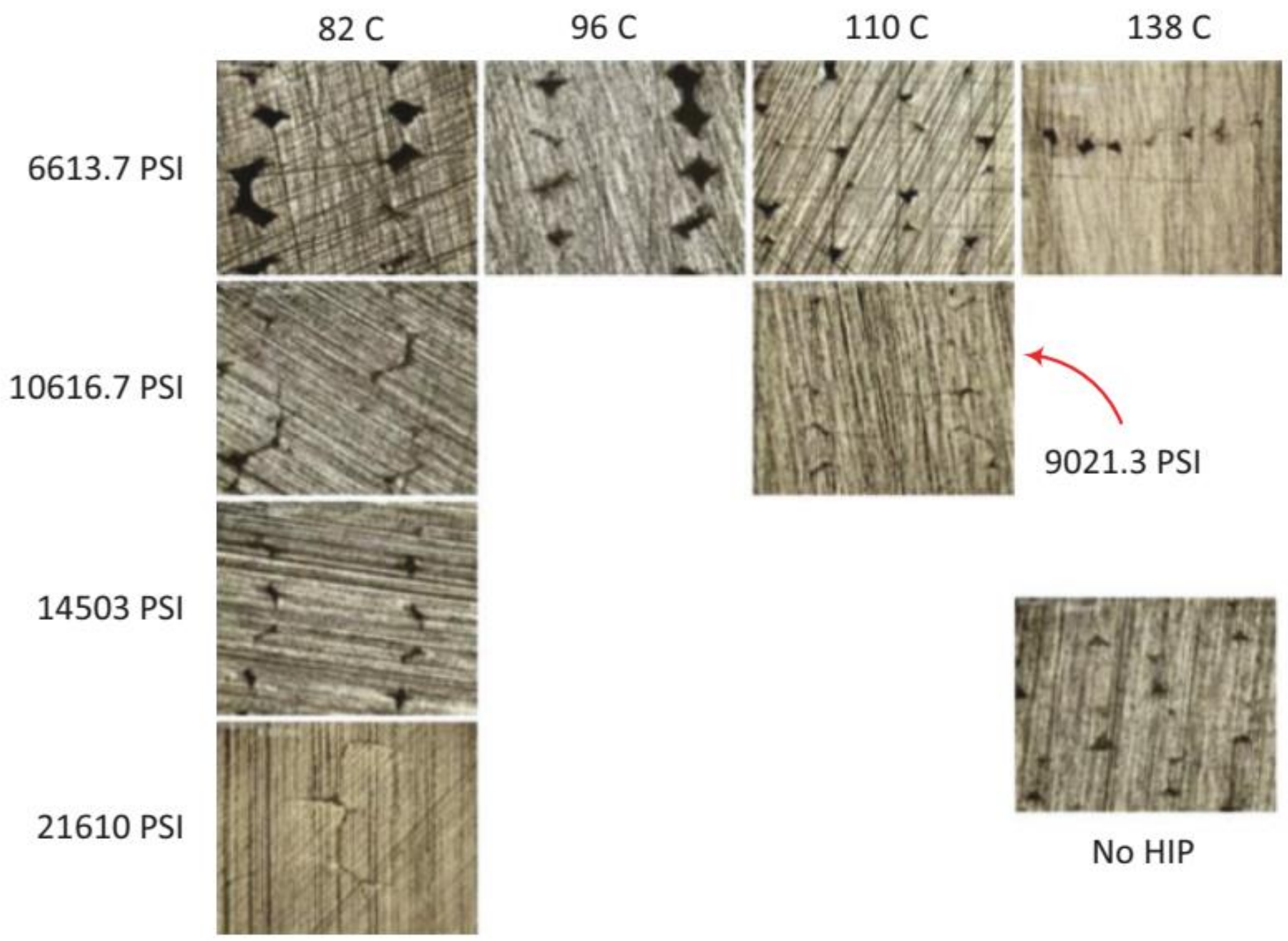


Fig. 16.18 HIP of polycarbonate to remove porosity [31]