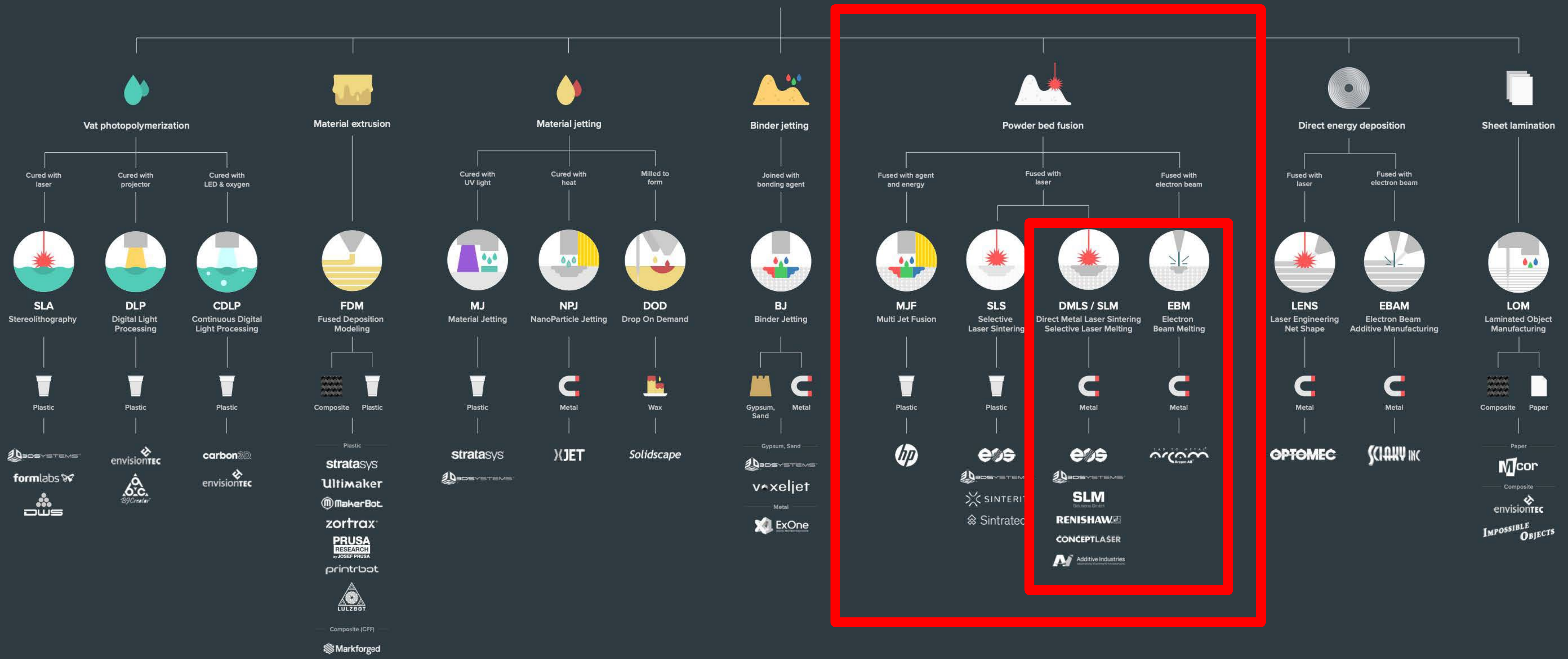
3D Printing & Additive Manufacturing
Powder Bed Fusion Processes

ADDITIVE MANUFACTURING TECHNOLOGIES



Powder Bed Fusion Processes

- One of the **first** commercialized AM process
- Selective Laser Sintering (SLS) is the first commercialized Powder Bed Fusion (PBF) process.
- Other PBF processes are variations of SLS
- **Main characteristics**
  - **Powders**
  - **Thermal source**
  - **Controlling powder fusion**
  - **Coating mechanism**

Powder Bed Fusion Processes

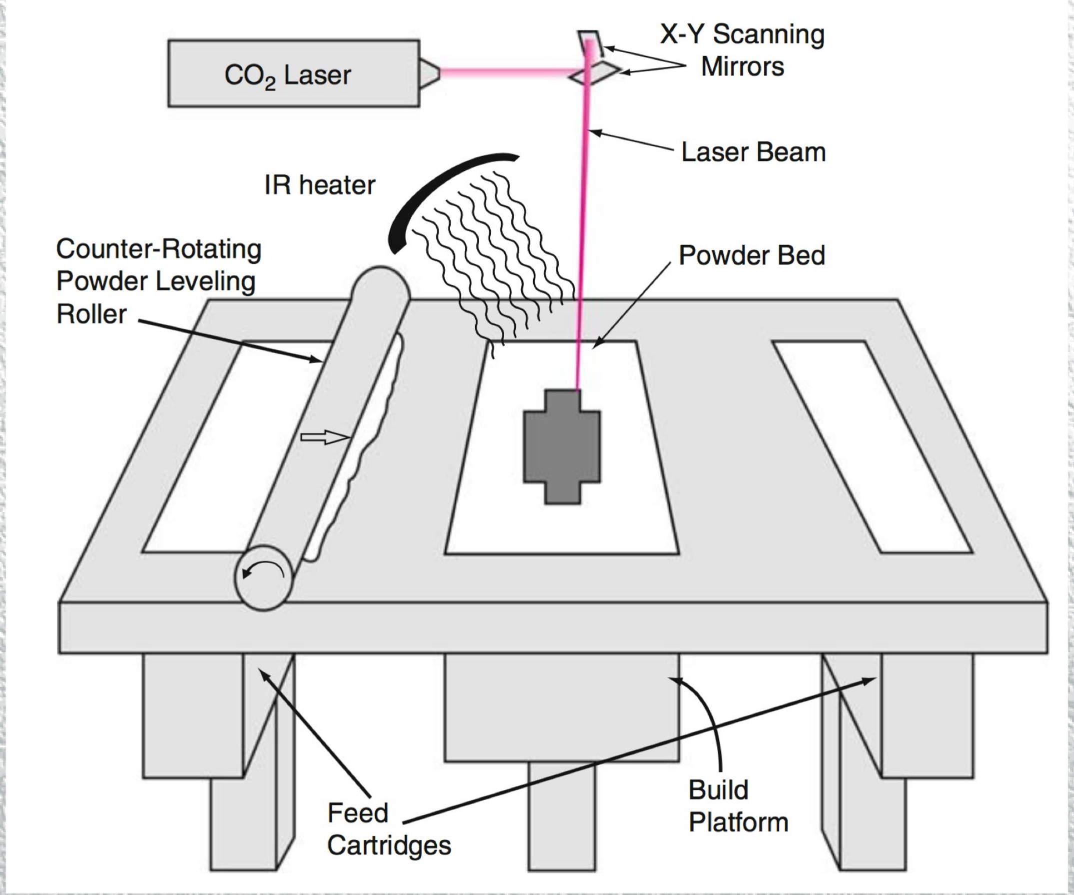


Fig. 5.1 Schematic of the Selective Laser Sintering process

Powder Fusion Mechanisms

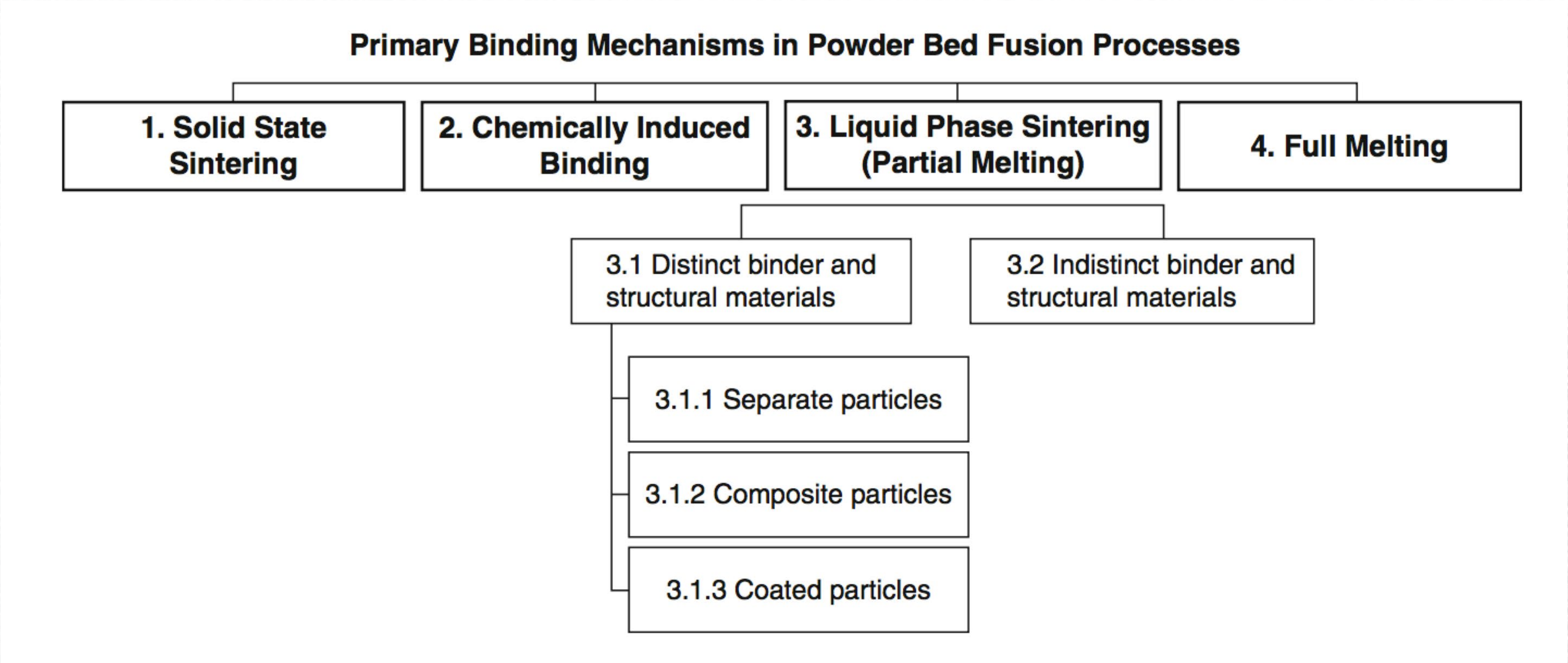


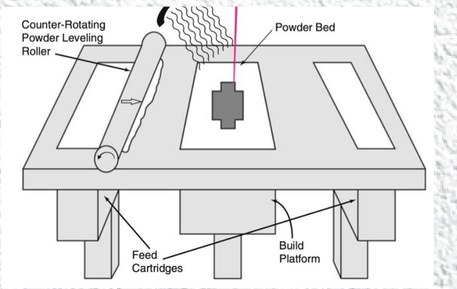
Fig. 5.5 Primary binding mechanisms in Powder Bed Fusion processes

Full Melting

- **Mostly used** with metal alloys and semi-crystalline polymers.
- **Entire region** of material melted to a depth exceeding the layer thickness.
- Effective at creating well-bonded, high-density structures
- For metal powder PBF processes, engineering alloys are fully melted.
- The rapid melting and solidification of these metal alloys results in **unique** properties.
- Better than cast or wrought parts made from identical alloys.

Powder Handling Challenges

- Several methods developed to avoid patented counter-rotating roller



- **Delivery systems** should meet the followings
  1. Powder reservoir of **sufficient** volume
  2. **Correct** amount of powder on the layer
  3. **Smooth**, thin, repeatable layer
  4. No **shear** forces on the previous layer

Powder Handling Challenges

- **Delivery system** should deal with the universal characteristics of powder feeding.

1. As particle size **decreases**, interparticle friction and **electrostatic** forces increase resulting in decrease in the flowability. Effective powder delivery system must make the powder flowable.
2. When the **surface** area to volume ratio of a particle increases, its surface energy increases and becomes more **reactive**. Certain powders must be kept in an **inert** atmosphere.

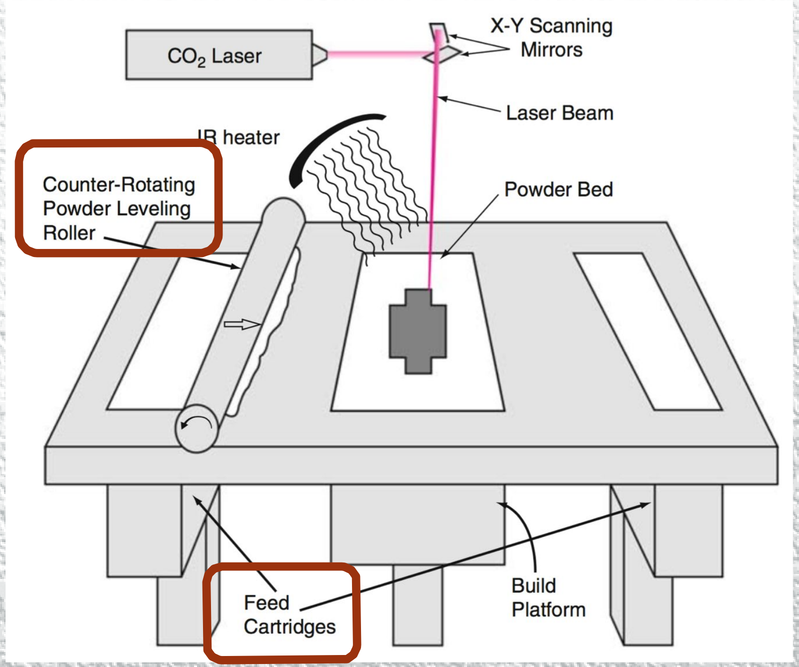
Powder Handling Challenges

- **Delivery system** should deal with the universal characteristics of powder feeding.

3. The powder delivery system should **minimize** the creation of **airborne** particles.
4. **Smaller** powder particle **sizes** enable better surface **finish**, higher accuracy, and thinner layers. Methods should feed the smallest possible powder particle sizes while minimizing the negative effects of these small powder particles.

Powder Handling Systems

- **Feed** cartridges up
- **Platform** down
- **Raised** powder pushed by the roller
- Counter-rotating action of the roller creates a wave of **powder**
- **Small** shear forces on the previous layer



Powder Handling Systems

- **Hopper** feeding system
- Powders fed from **above**
- **Blade or roller** can be integrated.
- **Ultrasonic vibration** can be used for feeding and spreading to fluidize powders.
- **Multiple hoppers** are used in multi-material powder bed processing.

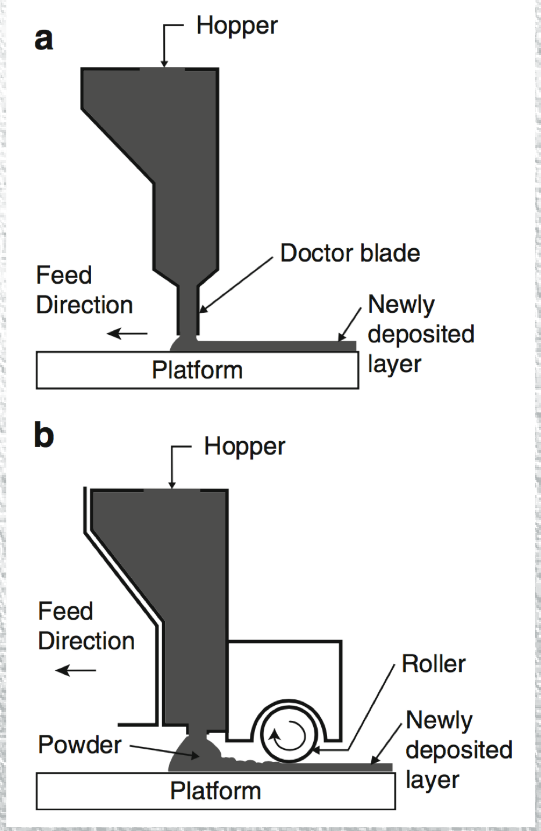


Fig. 5.6 Examples of hopper based powder delivery systems

Powder Recycling

- Elevated temperature sintering can cause particle grains in the loose powder bed to **fuse**.
- **Atmospheric** gases may also cause the same.
- **Elevated** temperatures can change the molecular weight of the polymer.
- These effects **change** the **properties** of the recycled powders.
- The simplest approach to this recycling problem is to **mix** a specific ratio of unused powder with used powders (1:1:1, 1/3 unused powder, 1/3 overflow/feed powder, and 1/3 build platform powder)

Approaches for Metal and Ceramic Parts

- Full melting
  - Metallic or ceramic powdered material is fully melted using a high-power laser or electron beam.

Variants of Powder Bed Fusion Processes

- **Powder** delivery method
- **Heating** process
- **Energy** input type
- **Atmospheric** conditions
- **Optics**

Laser-based Systems for Metals and Ceramics

- Selective Laser Melting (SLM)
- Metal powders are **difficult** to process than polymers.
- Rigid attachment of parts to a base plate at the bottom of the build platform
- 3D Micromac developed a unique two-material powder feeding mechanism.

Fig. 5.11 3D Micromac Powder Feed System

Laser-based Systems for Low-temperature Processing(Similar with high.)

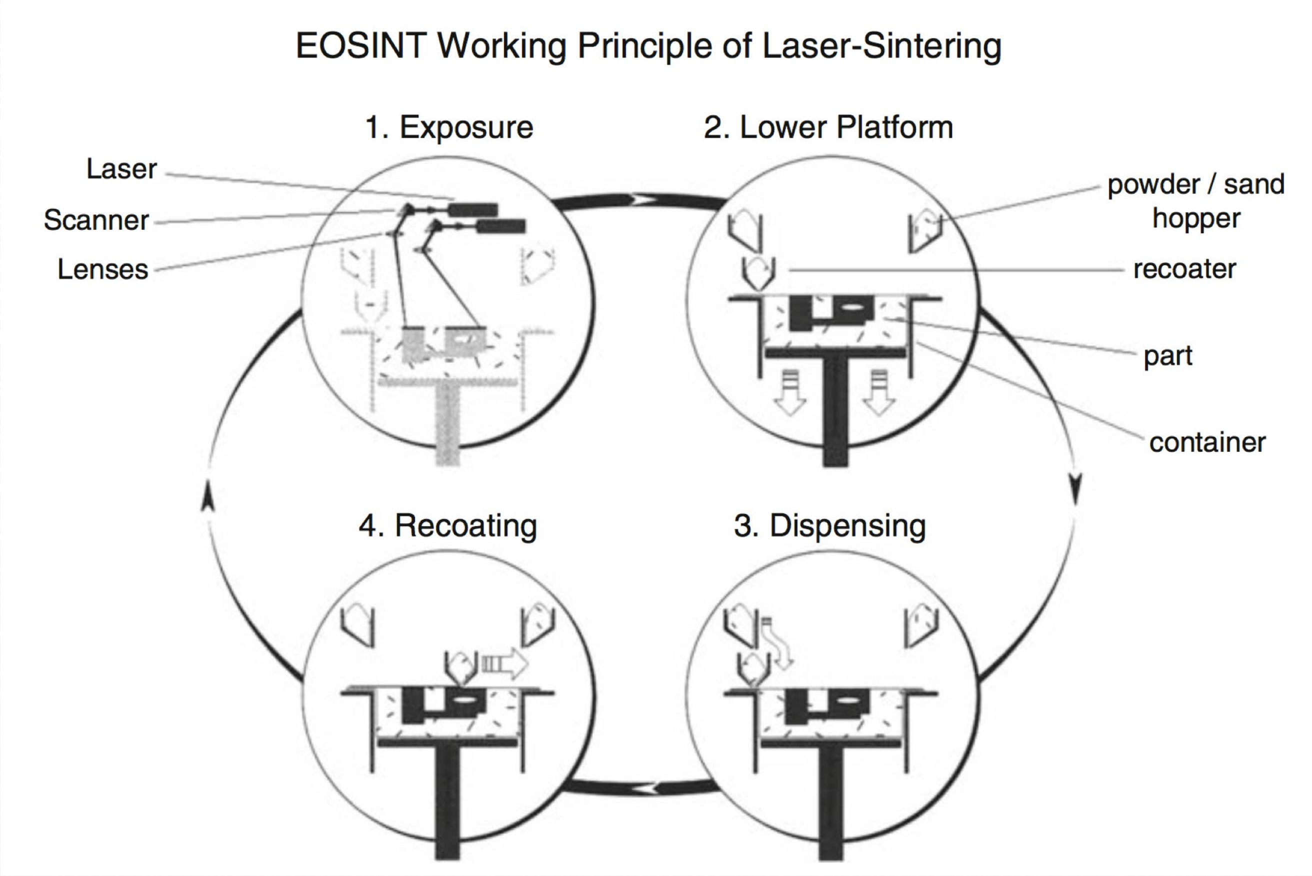


Fig. 5.9 EOSint Laser Sintering Schematic

Electron Beam Melting (EBM)

- **High-energy electron** beam used to induce fusion between metal powder particles

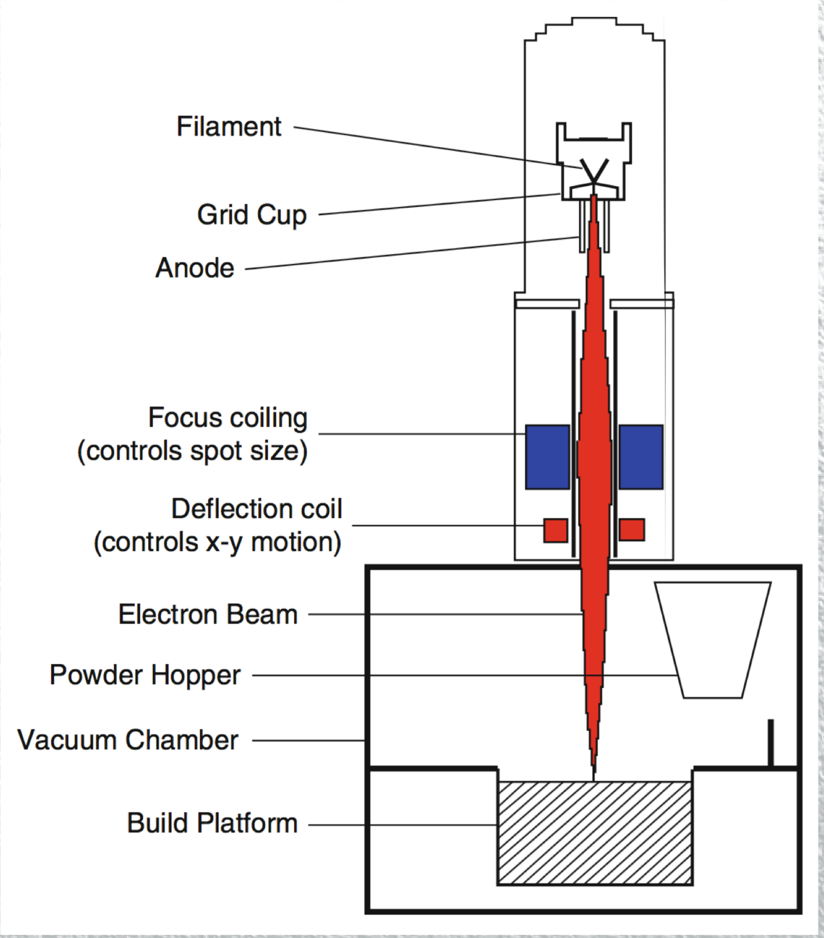


Fig. 5.13 Schematic of an EBM apparatus (courtesy Arcam)

Electron Beam Melting (EBM)

Table 5.1 Differences between EBM and SLM

Characteristic	Electron beam melting	Selective laser melting
Thermal source	Electron beam	Laser
Atmosphere	Vacuum	Inert gas
Scanning	Deflection coils	Galvanometers
Energy absorption	Conductivity-limited	Absorptivity-limited
Powder pre-heating	Use electron beam	Use infrared heaters
Scan speeds	Very fast, magnetically-driven	Limited by galvanometer inertia
Energy costs	Moderate	High
Surface finish	Moderate to poor	Excellent to moderate
Feature resolution	Moderate	Excellent
Materials	Metals (conductors)	Polymers, metals and ceramics

Electron Beam Melting (EBM)

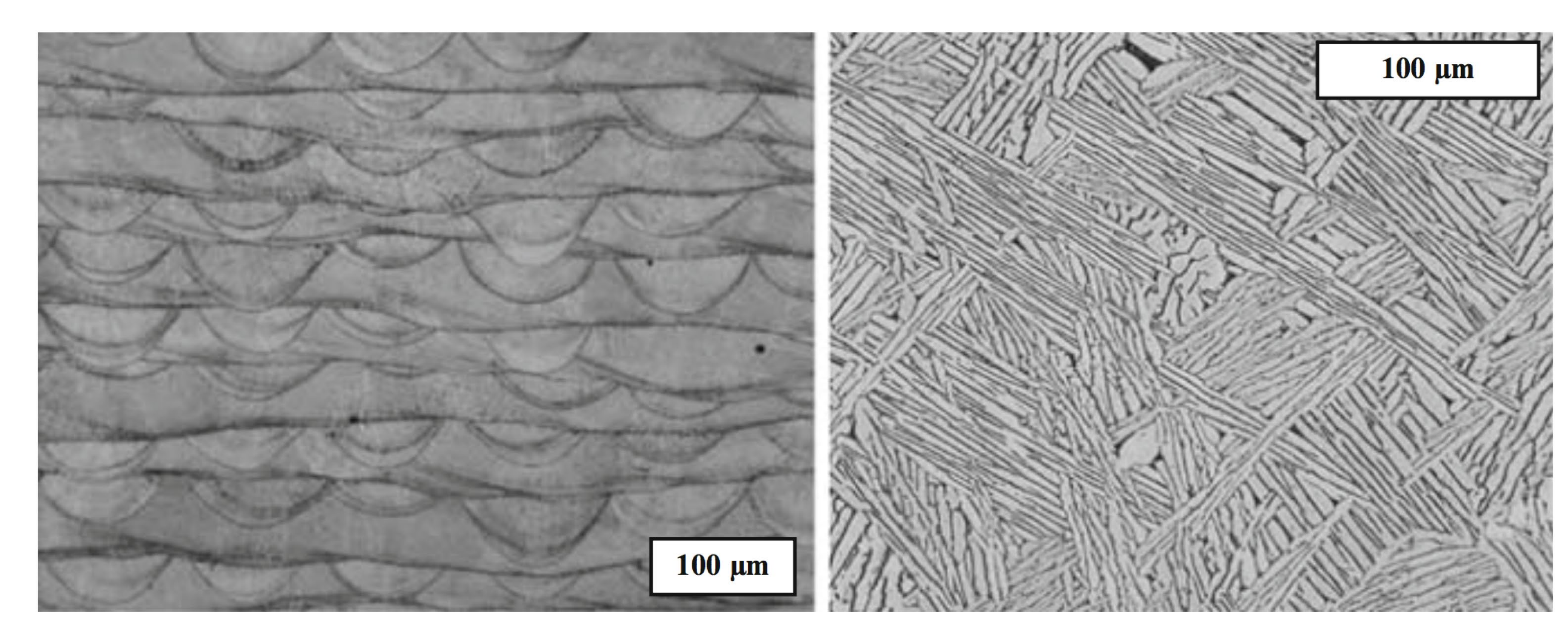


Fig. 5.14 Microstructure representatives of the current practice of SLM and EBM

Process Parameters

- Use of **optimum** process parameters is **extremely important**.
  - **Laser-related** parameters
  - **Scan-related** parameters
  - **Powder-related** parameters
  - **Temperature-related** parameters
- These parameters are strongly interdependent and are mutually interacting.
- Read the relations of these parameters!

Process Parameters

- **Scanning** modes
  - **Contour** mode (accuracy and surface finish)
  - **Fill** mode

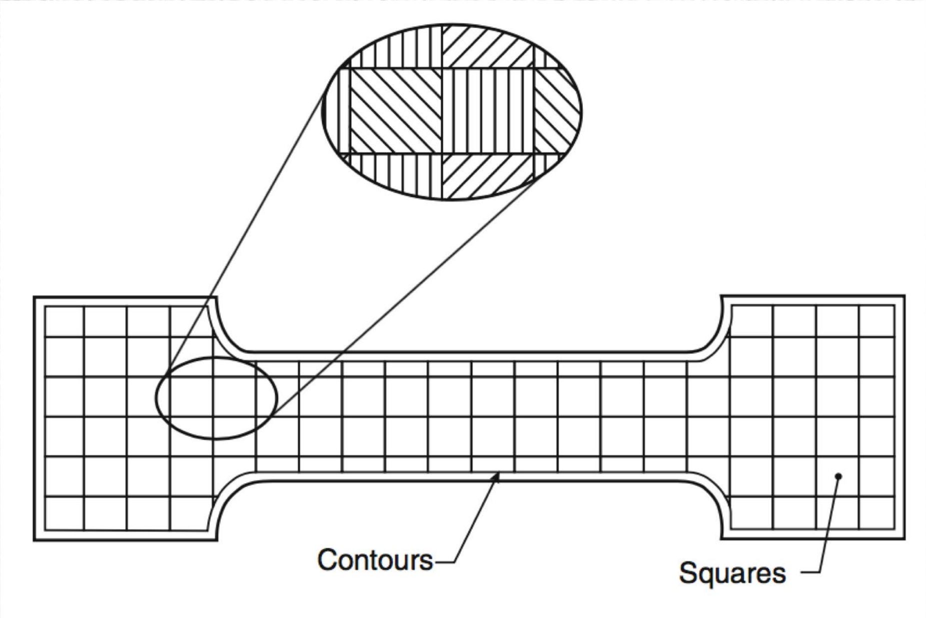


Fig. 5.16 Scan strategies employed in PBF techniques

Energy Correlations & Scan Patterns

- The **simplest** analytical approach
- E_A : Applied energy density
- P: Laser power
- U: Scan velocity
- SP: Scan spacing

$$E_A = \frac{P}{U \times SP}$$

  - For SLS, typical scan spacing values are ~100 μm, whereas typical laser spot sizes are ~300 μm. Thus, typically every point is scanned by **multiple passes** of the laser beam.

Materials

- Materials that can be **melted and resolidified** can be used.
  - **Thermoplastic** materials well-suited
  - **Polyamide-based** powders
  - **Metal** powders
- Mechanical properties of SLS parts produced using polyamide powders approach those of injection molded thermoplastics parts, but with significantly reduced elongation and unique microstructures.
- Elastomeric thermoplastic polymers are available for producing highly flexible parts with rubber-like characteristics.

Capabilities and Limitations

- Loose powder bed is a sufficient **support** material
  - Saves time during manufacturing and post-processing
  - Intricate shapes
- Accuracy and surface finish is worse than Photopolymerization processes.
- Materials with **low thermal** conductivity result in better accuracy.
- Part construction **time** is longer than other AM processes.
- **Multiple** parts can be built at a time.

Conclusions

- One of the first AM processes
- Popular
- Prototyping
- End-use applications
- **Competitive** for low-to-medium volume geometrically complex parts
- Metal-based processes are growing.
  - Aerospace
  - Biomedical

Generalized AM Process Chain

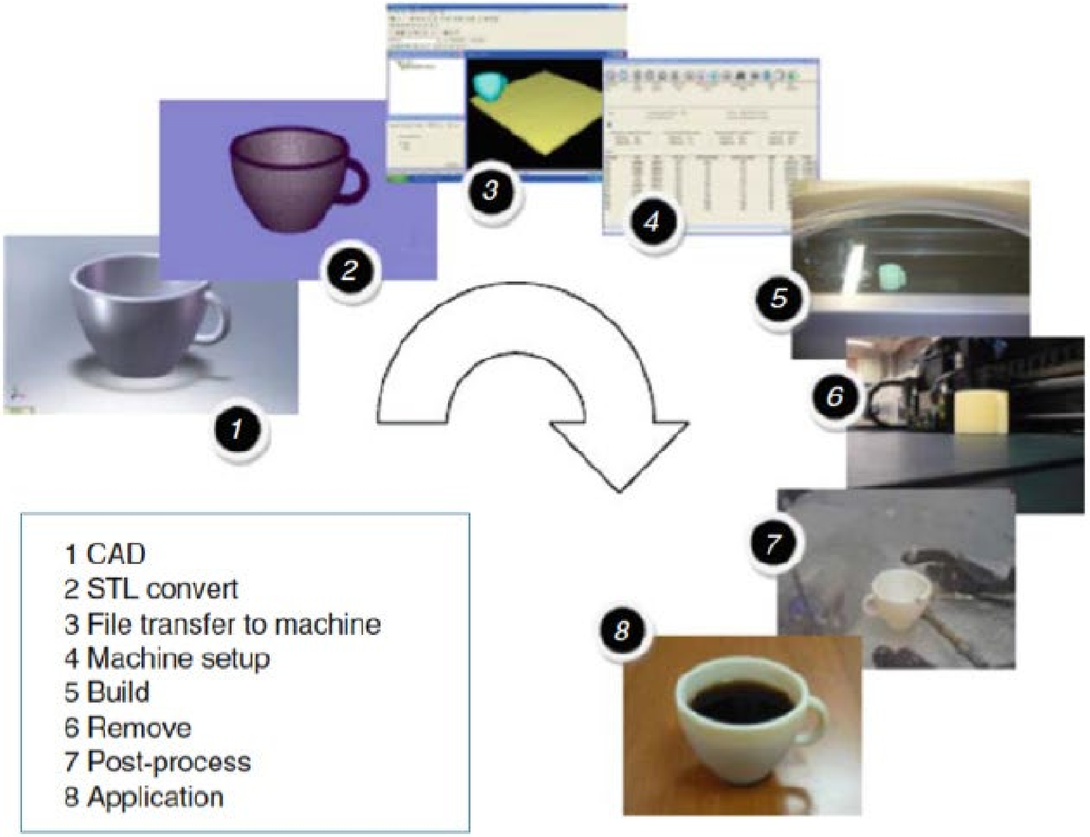


Fig. 3.1 The eight stages of the AM process

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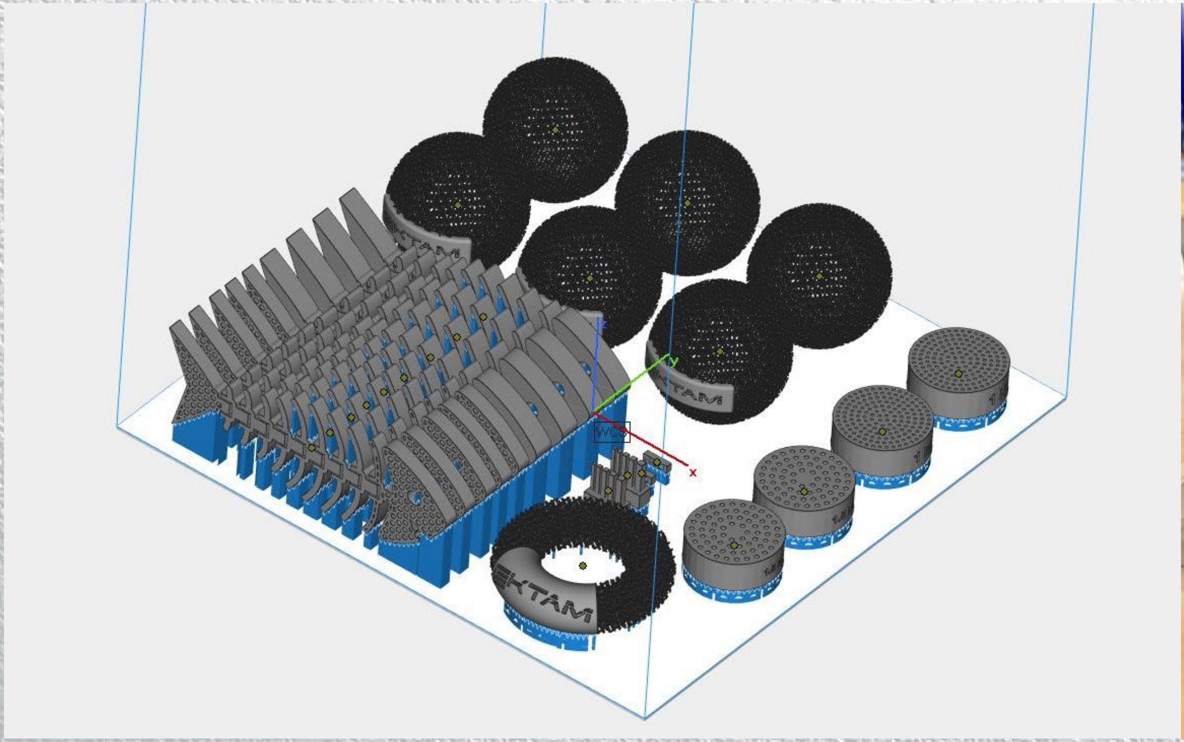

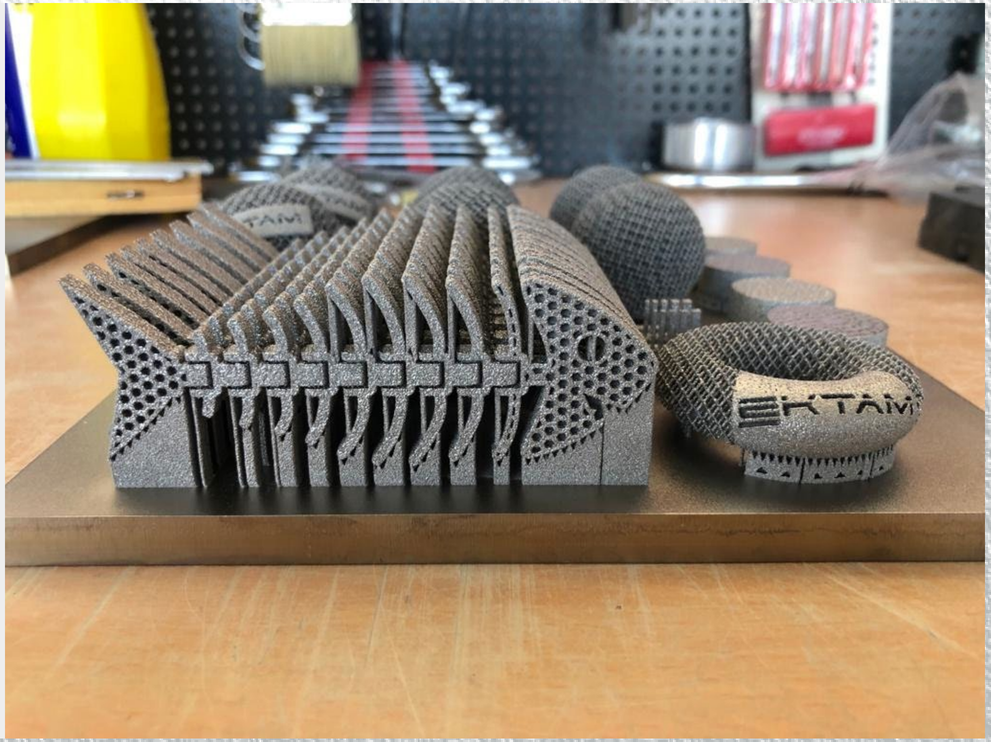

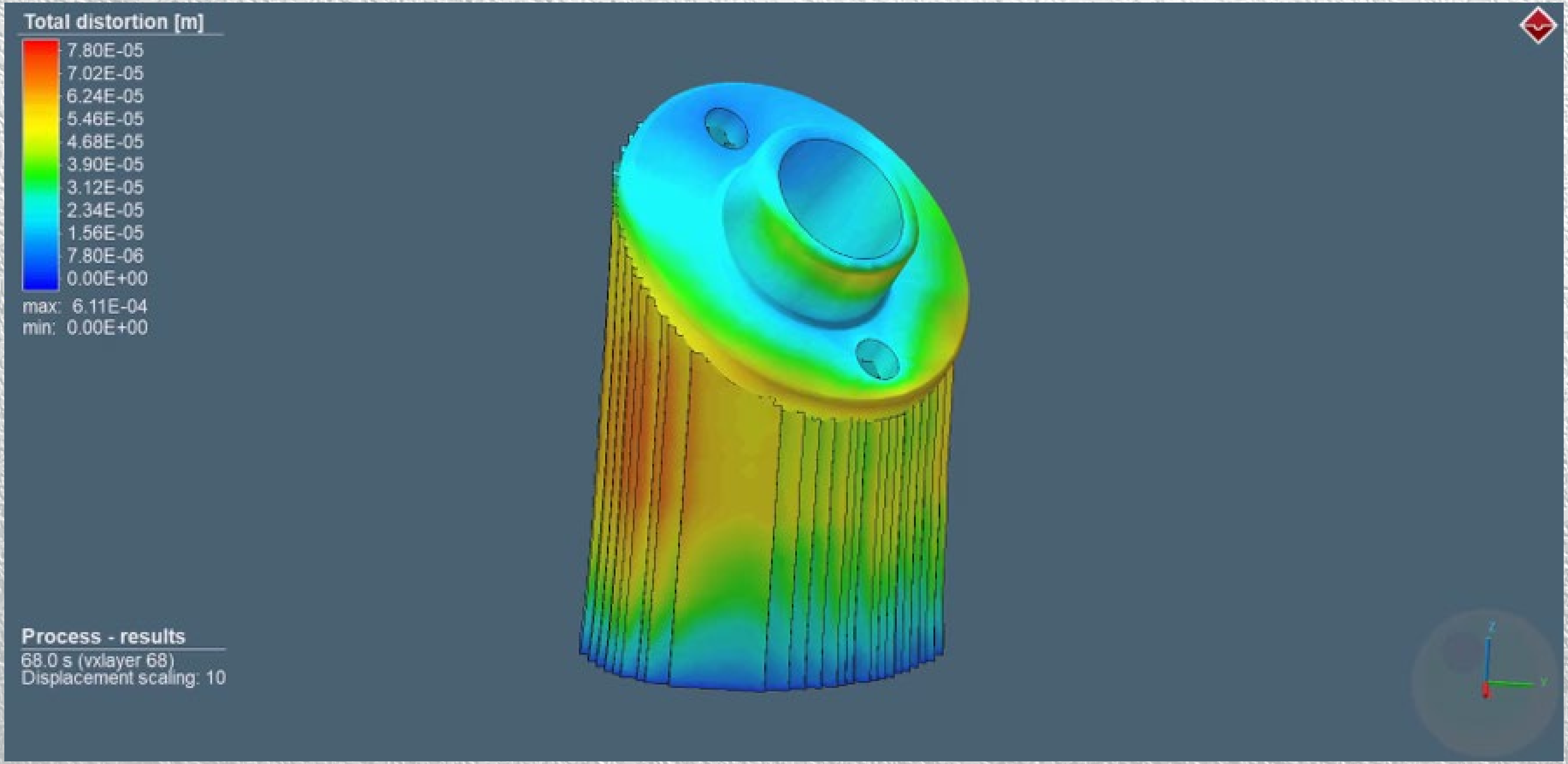
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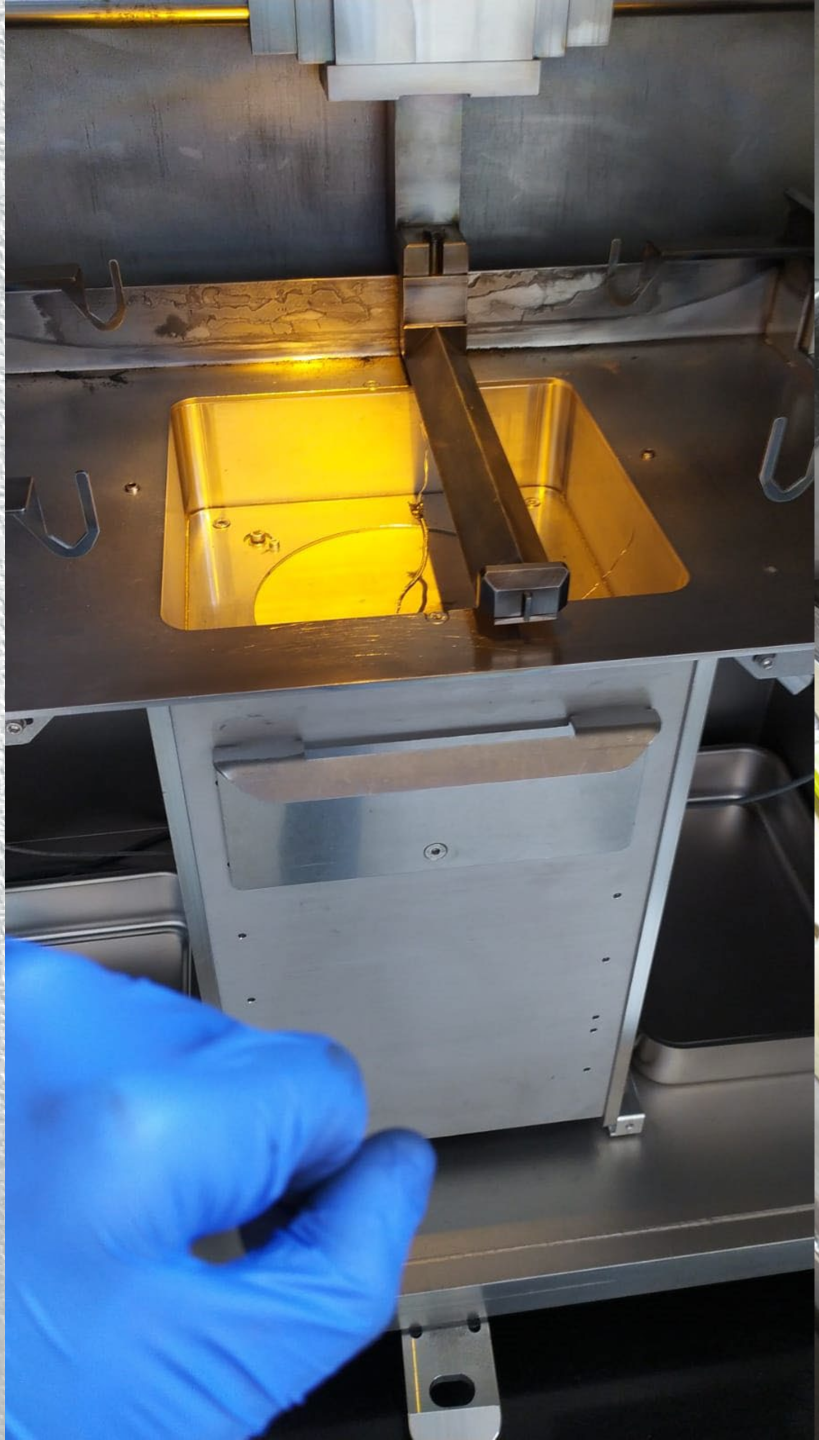
7.80E-05
7.02E-05
6.24E-05
5.46E-05
4.68E-05
3.90E-05
3.12E-05
2.34E-05
1.56E-05
7.80E-06
0.00E+00
max: 6.11E-04
min: 0.00E+00
Process - results
68.0 s (vxlayer 68)
Displacement scaling: 10

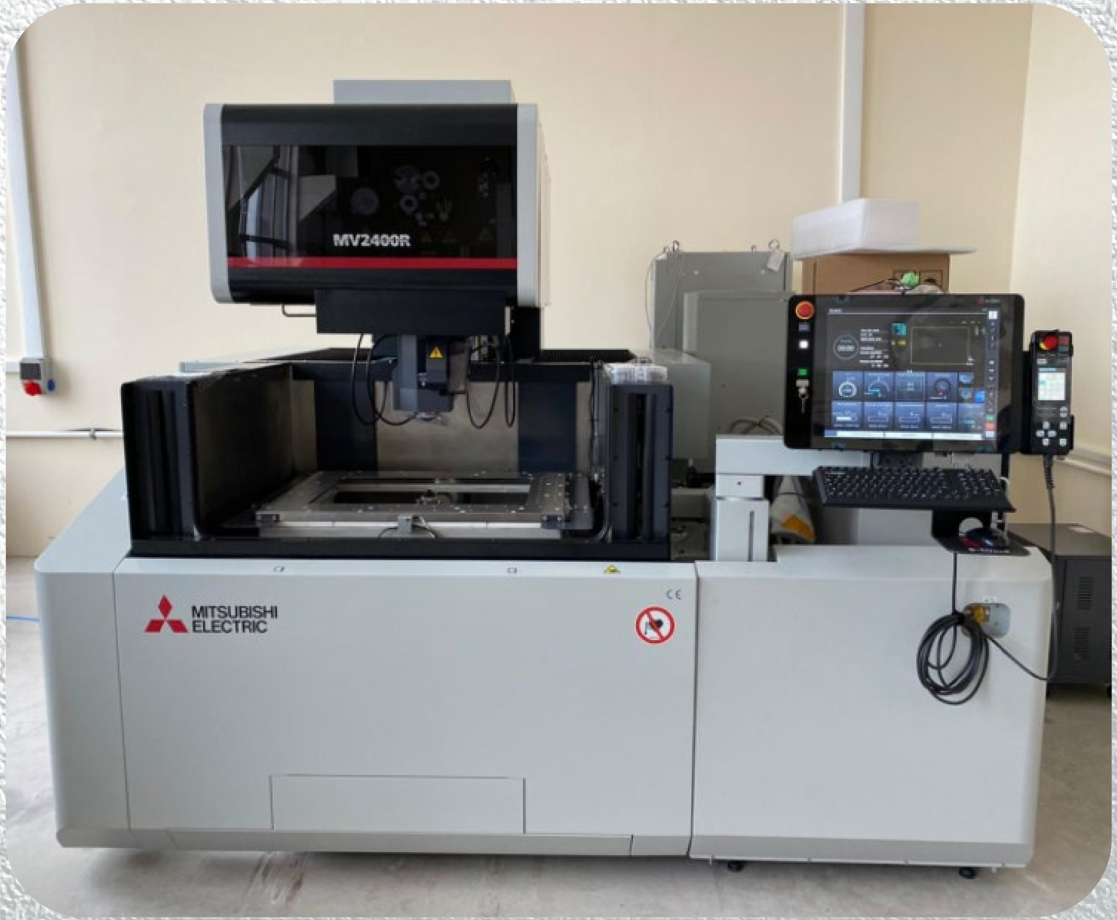


Arcam A2X EBM Machine

Concept Laser M2 Cusing SLM Machine

ERMAKSAN Ena Vision 250 SLM Machine

Wire EDM Machine



Surface Grinding Machine

Example of Concept Laser M2 Cusing SLM Machine

REFERENCES:

- [Fig.5.1, Fig.5.5, Fig.5.6, Fig.5.11, Fig.5.9, Fig.5.13, Fig.3.1]Gibson, Ian, David Rosen, and Brent Stucker. *Additive manufacturing technologies: 3D printing,rapid prototyping, and direct digital manufacturing*. Springer, 2014.
- EKTAM Files

END.