Global Manufacturing

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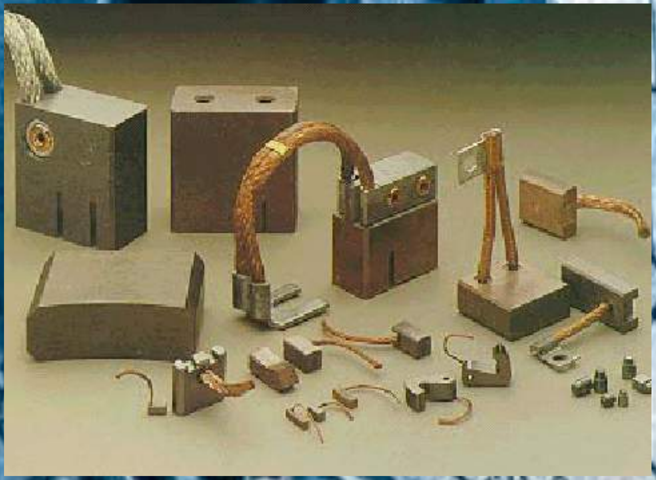
Mechanical Engineering Department – POLI/COPPE/UFRJ

Workpiece Presentation




Powder Metallurgy and Additive Manufacturing [#7]

Powder Metallurgy

- PM parts can be mass-produced to net shape or near net shape
- The PM process itself involves very little waste of material; about 97% of the starting powders are converted to product (no sprues, runners, and risers that are wasted material)
- Porous Metals: Parts having a specified level of porosity can be made. (filters, oil-impregnated bearings and gears can be made)
- Certain metals that are difficult to fabricate by other methods can be shaped by powder metallurgy: Tungsten is an example. Tungsten filaments used in incandescent lamp bulbs are made using PM technology.
- Tolerances of 0.13 mm (0.005 in) [Smaller then Casting]
- PM production methods can be automated for economical production.

Powder Metallugy - Limitations

- Cost for tooling and equipment (high)
- Cost of metallic powders (expensive)
- Difficulties with storing and handling metal powders (such as degradation of the metal over time, and fire hazards with particular metals).
- Limitations on part geometry because metal powders do not readily flow laterally in the die during pressing, and allowances must be provided for ejection of the part from the die after pressing.
- Variations in material density throughout the part may be a problem in PM, especially for complex part geometries.

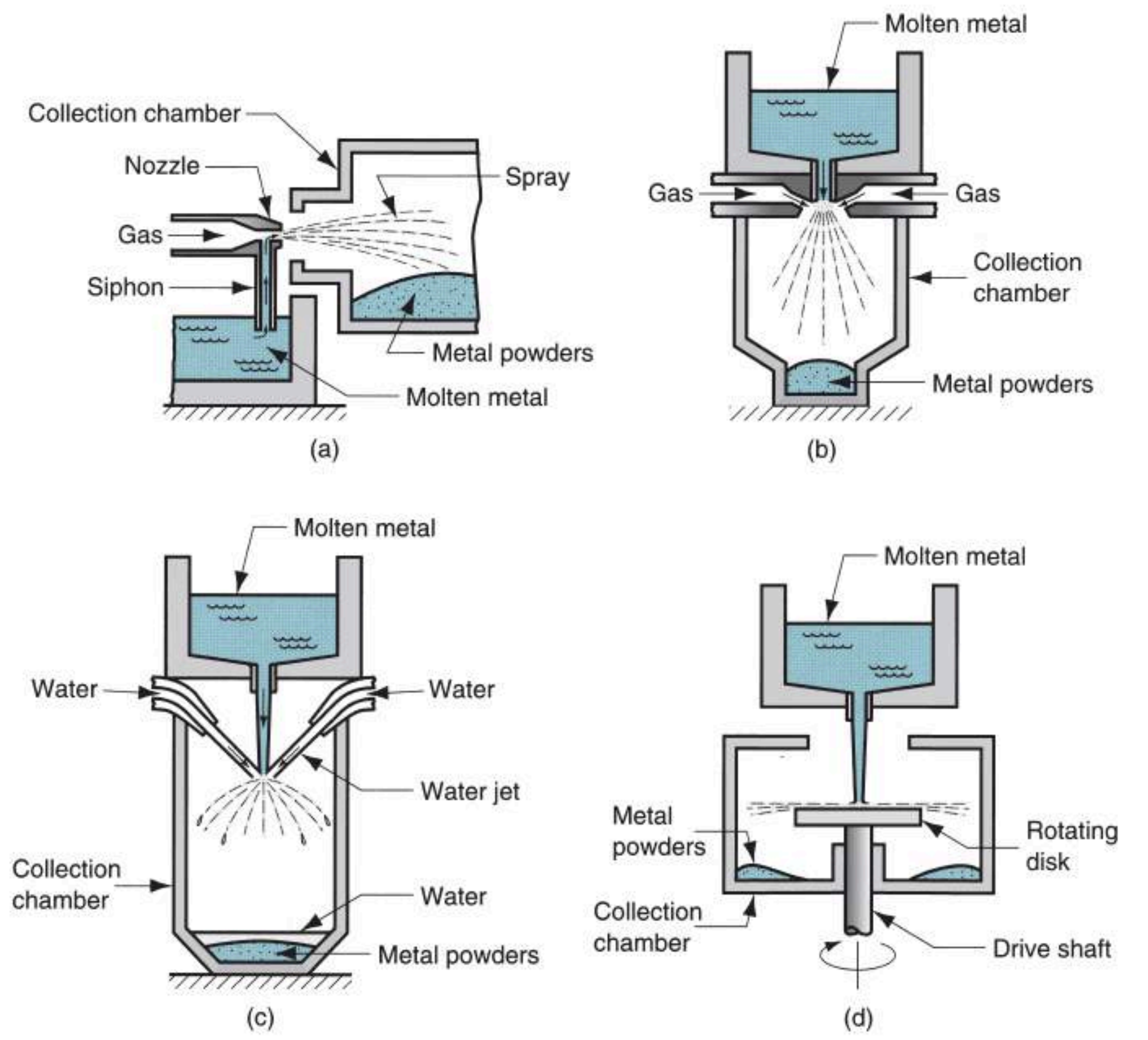
PRODUCTION OF METALLIC POWDERS - Atomization

Atomization: conversion of molten metal into a spray of droplets that solidify into powders

Gas atomization: a high-velocity gas stream (air or inert gas) is utilized to atomize the liquid metal.

Water atomization: for metals that melt below 1000C. Cooling is more rapid powder shape is irregular.

Centrifugal atomization: liquid metal stream pours onto a rapidly rotating disk that sprays the metal in all directions to produce powders



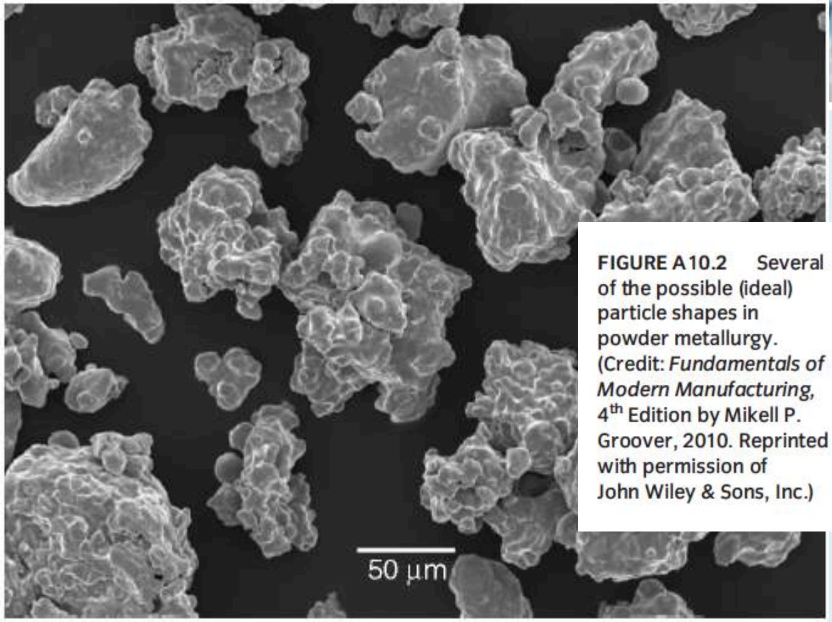


FIGURE 10.3 Iron powders produced by water atomization. Photo courtesy of T. F. Murphy and Hoeganaes Corporation.

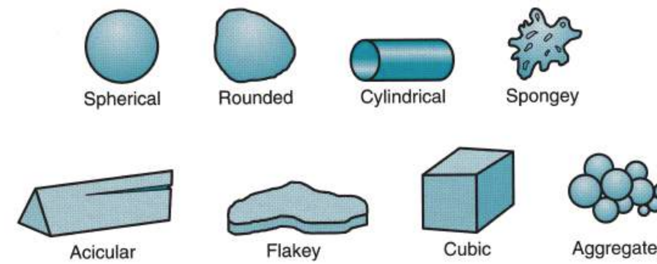


FIGURE A10.2 Several of the possible (ideal) particle shapes in powder metallurgy. (Credit: *Fundamentals of Modern Manufacturing*, 4th Edition by Mikell P. Groover, 2010. Reprinted with permission of John Wiley & Sons, Inc.)

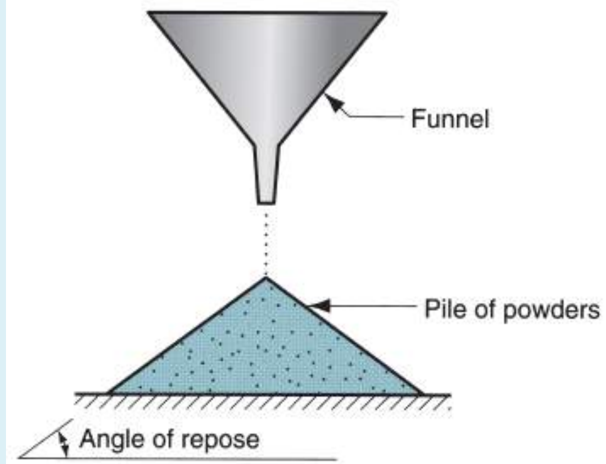


FIGURE A10.3 Interparticle friction as indicated by the angle of repose of a pile of powders poured from a narrow funnel. Larger angles indicate greater interparticle friction. (Credit: *Fundamentals of Modern Manufacturing*, 4th Edition by Mikell P. Groover, 2010. Reprinted with permission of John Wiley & Sons, Inc.)

Blending

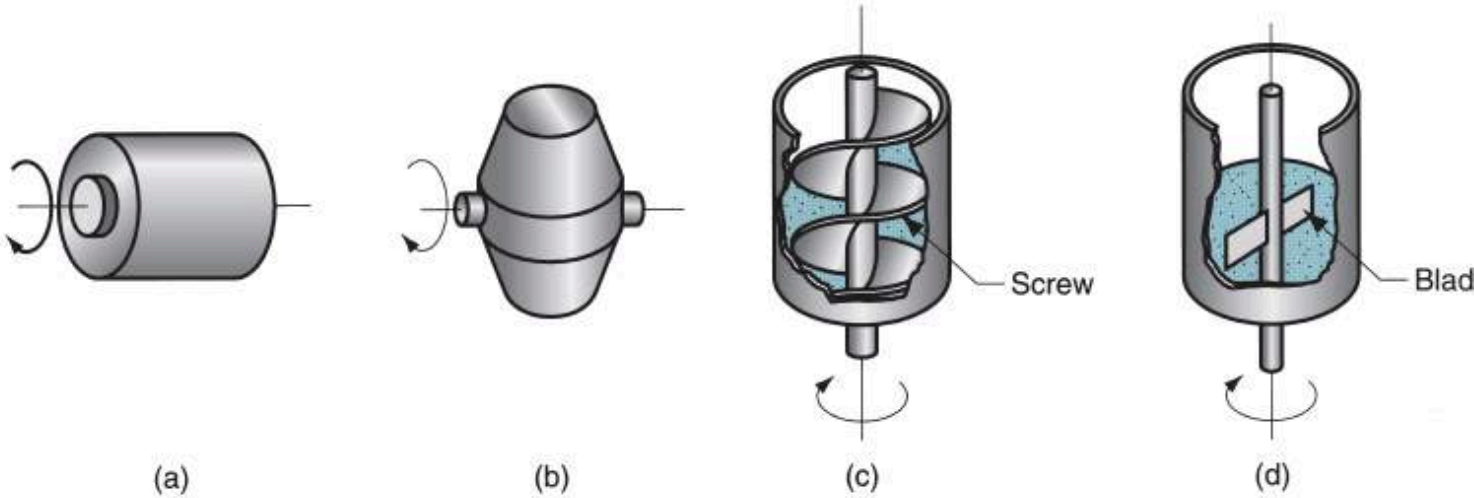


FIGURE 10.5 Several blending and mixing devices: (a) rotating drum, (b) rotating double-cone, (c) screw mixer, and (d) blade mixer. (Credit: *Fundamentals of Modern Manufacturing*, 4th Edition by Mikell P. Groover, 2010. Reprinted with permission of John Wiley & Sons, Inc.)

Other ingredients are usually added to the metallic powders during the blending:

(1) lubricants, such as stearates of zinc and aluminum, in small amounts to reduce friction between particles and at the die wall during compaction;
(2) binders, which are required in some cases to achieve adequate strength in the pressed but unsintered part;
(3) deflocculants, which inhibit agglomeration of powders for better flow characteristics during subsequent processing

Compaction

In compaction, high pressure is applied to the powders to form them into the required shape.

Pressing: The conventional compaction method in which opposing punches squeeze the powders contained in a die. GREEN COMPACT is produced.

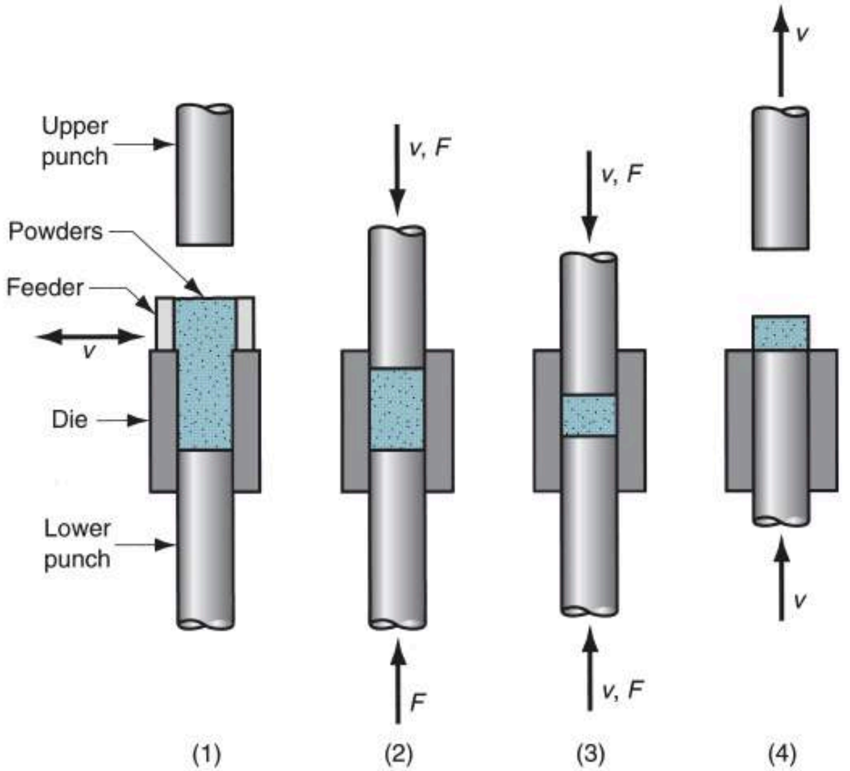
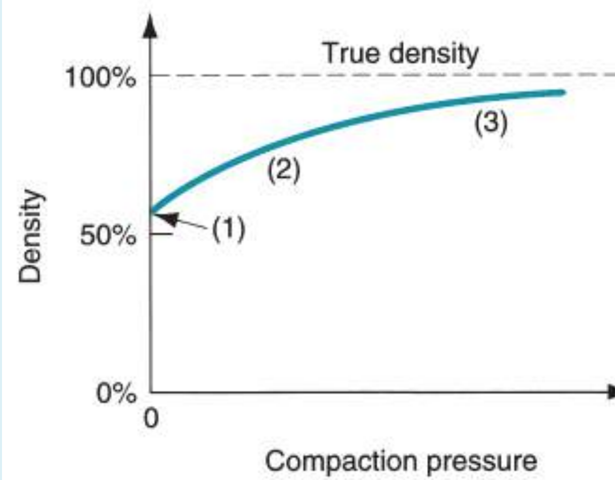
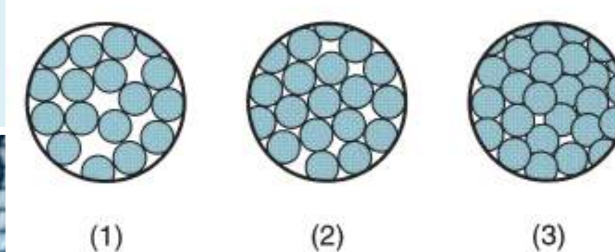


FIGURE 10.6 Pressing, the conventional method of compacting metal powders in PM: (1) filling the die cavity with powder, done by automatic feed in production, (2) initial, and (3) final positions of upper and lower punches during compaction, and (4) ejection of part. (Credit: *Fundamentals of Modern Manufacturing*, 4th Edition by Mikell P. Groover, 2010. Reprinted with permission of John Wiley & Sons, Inc.)





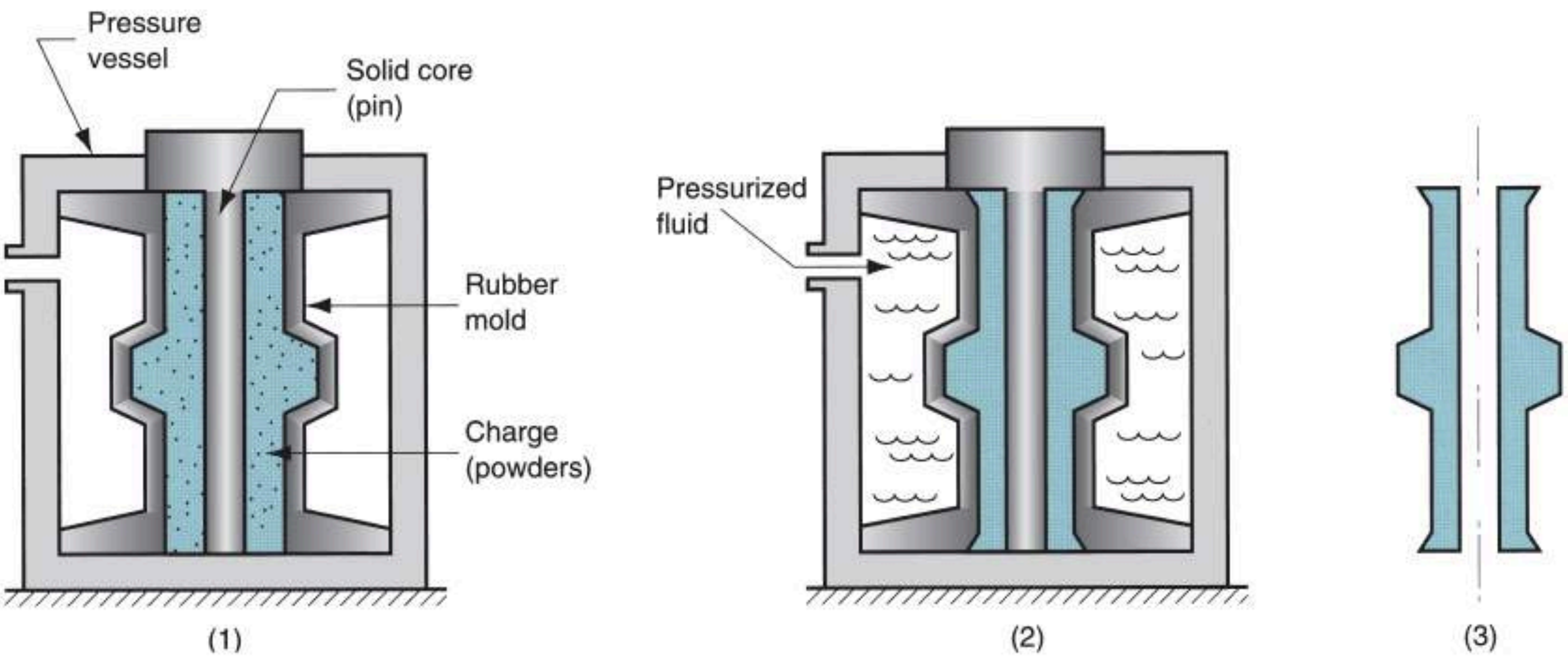
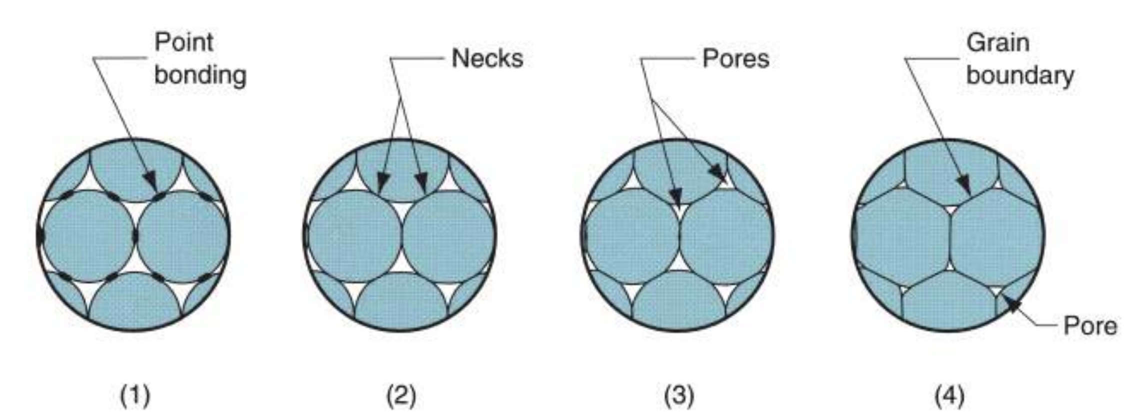


FIGURE 10.11 Cold isostatic pressing: (1) powders are placed in the flexible mold; (2) hydrostatic pressure is applied against the mold to compact the powders; and (3) pressure is reduced and the part is removed. (Credit: *Fundamentals of Modern Manufacturing*, 4th Edition by Mikell P. Groover, 2010. Reprinted with permission of John Wiley & Sons, Inc.)

Sintering

Sintering is a heat treatment operation performed on the compact to bond its metallic particles, thereby increasing strength and hardness. The treatment is usually carried out at temperatures between 0.7 and 0.9 of the metal's melting point (absolute scale).



Shrinkage is generally predictable when processing conditions are closely controlled.

The green compact consists of many distinct particles, each with its own individual surface, and so the total surface area contained in the compact is very high. Under the influence of heat, the surface area is reduced through the formation and growth of bonds between the particles, with associated **reduction in surface energy**. The finer the initial powder size, the higher the total surface area, and the greater the driving force behind the process.

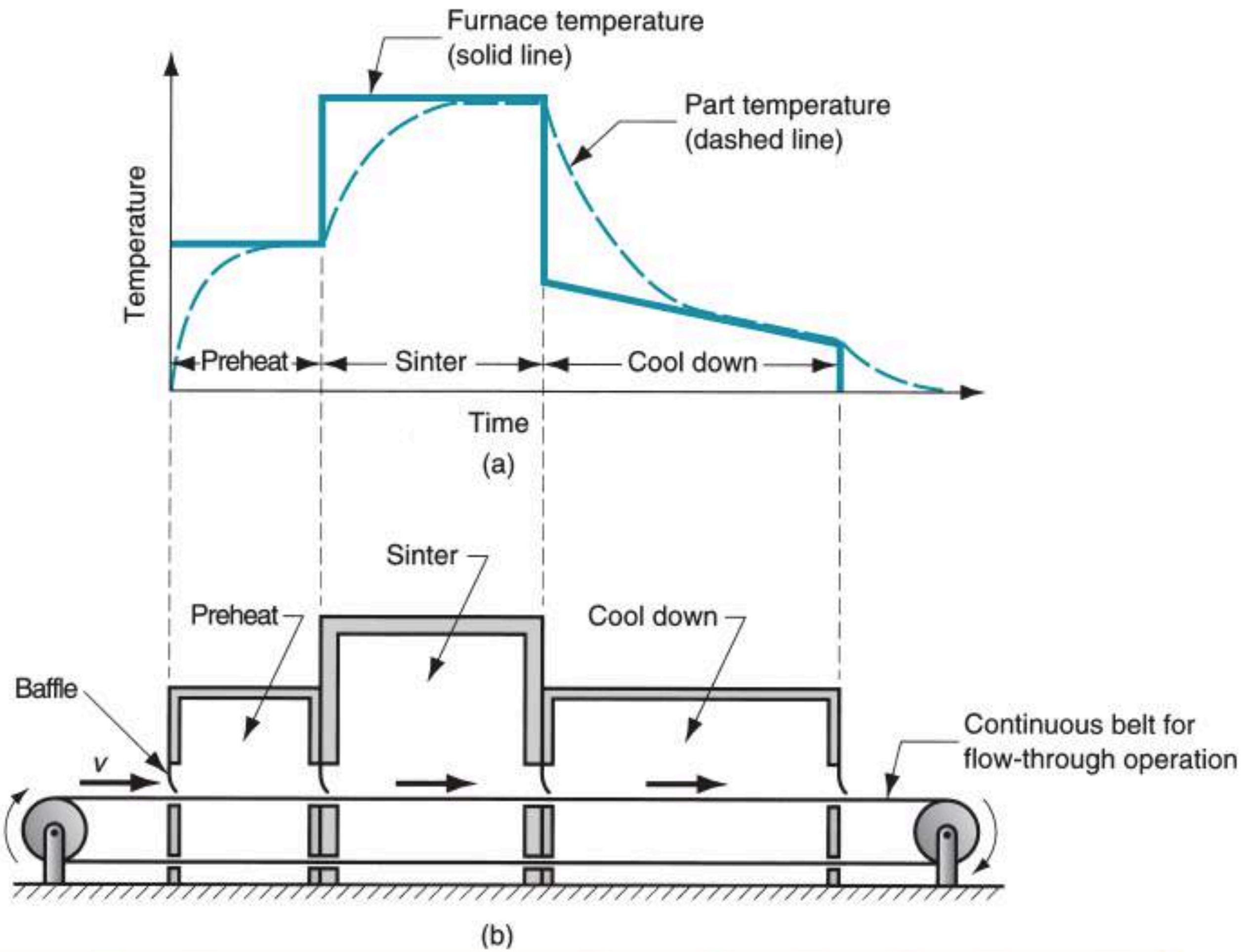
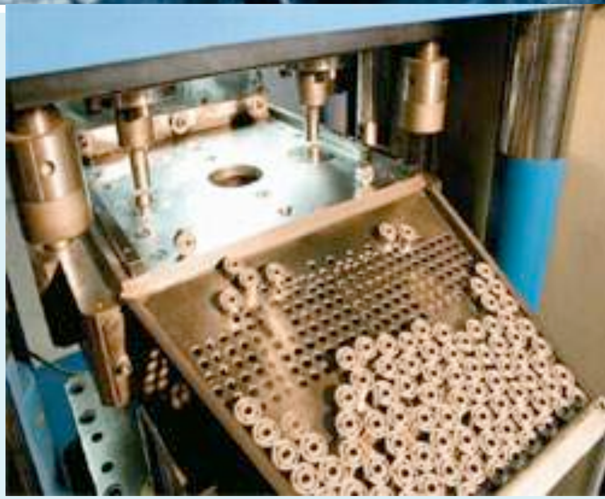
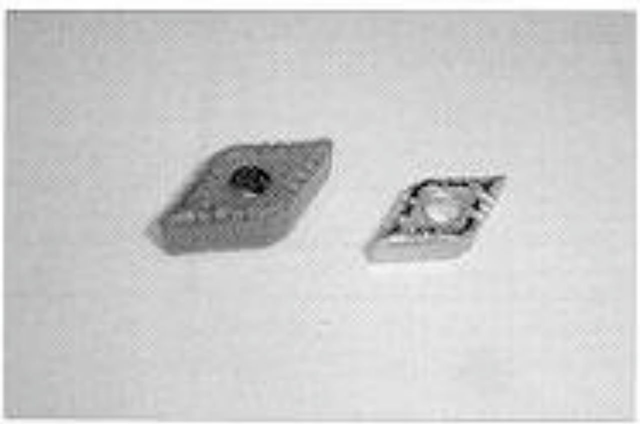


FIGURE 10.10
(a) Typical heat treatment cycle in sintering; and (b) schematic cross section of a continuous sintering furnace. (Credit: *Fundamentals of Modern Manufacturing*, 4th Edition by Mikell P. Groover, 2010. Reprinted with permission of John Wiley & Sons, Inc.)

TABLE 10.1 Typical sintering temperatures and times for selected powder metals.

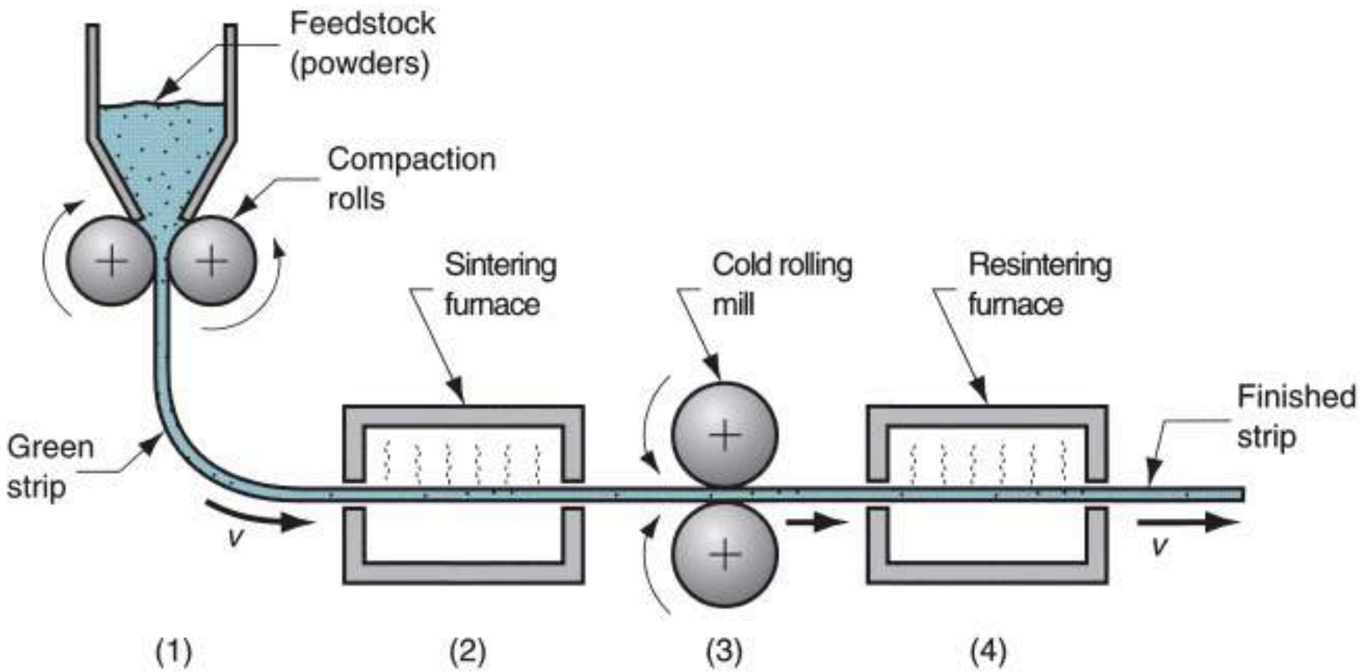
Metal	Sintering Temperatures °C	Sintering Temperatures °F	Typical Time
Brass	850	1600	25 min
Bronze	820	1500	15 min
Copper	850	1600	25 min
Iron	1100	2000	30 min
Stainless steel	1200	2200	45 min
Tungsten	2300	4200	480 min






Compactação
Sinterização

FIGURE 10.12 Powder rolling: (1) powders are fed through compaction rolls to form a green strip; (2) sintering; (3) cold rolling; and (4) resintering. (Credit: *Fundamentals of Modern Manufacturing*, 4th Edition by Mikell P. Groover, 2010. Reprinted with permission of John Wiley & Sons, Inc.)



- Powder injection molding (PIM),
- Powder Rolling,
- Powder Extrusion,
- Powder Forging
- Hot Pressing * (compact +Sint)
- Spark Sintering * (compact +Sint)

Additive Manufacturing

Rapid Prototyping

Rapid prototypinG is a family of fabrication methods to make engineering prototypes in minimum possible lead times based on a computer-aided design (CAD) model of the item.

The traditional method of fabricating a prototype part is machining, which can require significant lead times!

(1) material removal processes

(2) material addition processes: adding layers of material one at a time to build the solid part from bottom to top. (LAYERWISE MANUFACTURING)

Starting materials include:

- (1) liquid monomers and polymers that are cured layer by layer into solid parts,
- (2) powders that are aggregated and bonded layer by layer, and
- (3) solid sheets that are laminated to create the solid part.

Additive Manufacturing

Geometric modeling.

- modeling the component on a CAD system to define its enclosed volume. Solid modeling is the preferred technique because it provides a complete and unambiguous mathematical representation of the geometry. Important issue is to distinguish the interior (mass) of the part from its exterior, and solid modeling provides for this distinction.

Tessellation

- In this step, the CAD model is converted into a format that approximates its surfaces by triangles or polygons, with their verticesarranged to distinguish the object's interior from its exterior. The common tessellationformat used in rapid prototyping is STL,2 which has become the de facto standard input format for nearly all RP systems.

Slicing of the model into layers.

- In this step, the model in STL file format is sliced into closely spaced parallel horizontal layers. These layers are subsequentlyused by the RP system to construct the physical model in x-y plane orientation, and the layering procedure occurs in the z-axis direction. For each layer, a curing path is generated, called the STI file, which is the path that will be followed by the RP system to cure (or otherwise solidify) the layer.

Additive Manufacturing

Thickness Control
Stair-stepping
Surface Finishing
Precision
Suports
Builting Time

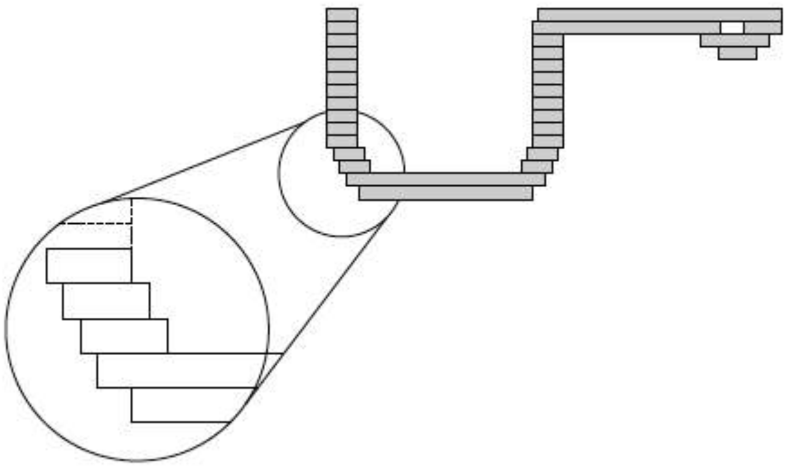


FIGURE 19-3 Building by layers results in stairstepping of curved surfaces and rounded corners.

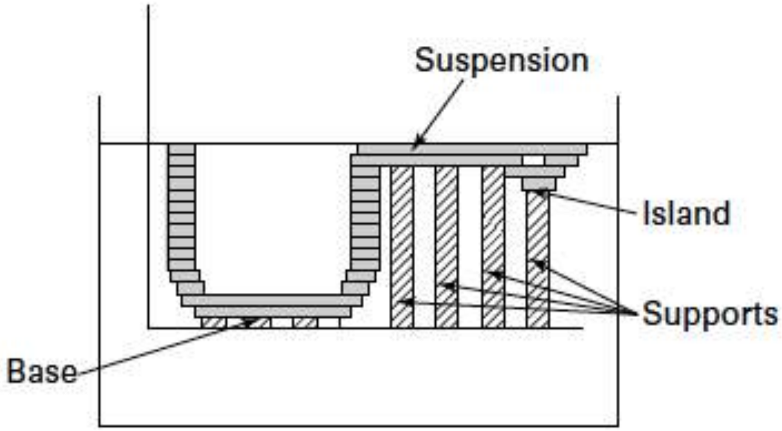


FIGURE 19-7 Many of the additive manufacturing processes require the use of bases and supports.

VOXEL GEOMETRY

Voxel geometry: is a useful concept in understanding the scanning-types of layerwise deposition. A voxel is a volume element and is the three-dimensional equivalent of the pixel (picture element) in a two-dimensional image. It describes the depth, width, and breadth of material that is effectively being altered by the energy or deposition being scanned. As such, the voxel geometry determines the thickness of layers, the distance between adjacent scans, and ultimately the number of layers and scans needed to complete a part, as well as the resultant surface finish. To understand the capabilities of various processes, it is important to understand how voxel geometry is affected by changes in the material and process parameters.

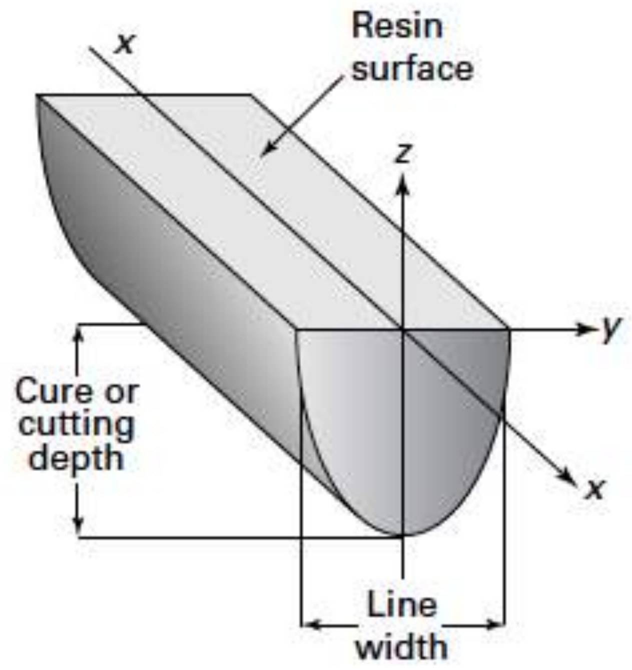


FIGURE 19-6 In stereolithography, the laser produces a cure line of photopolymer, where the width, depth, area, and profile are determined by the voxel.

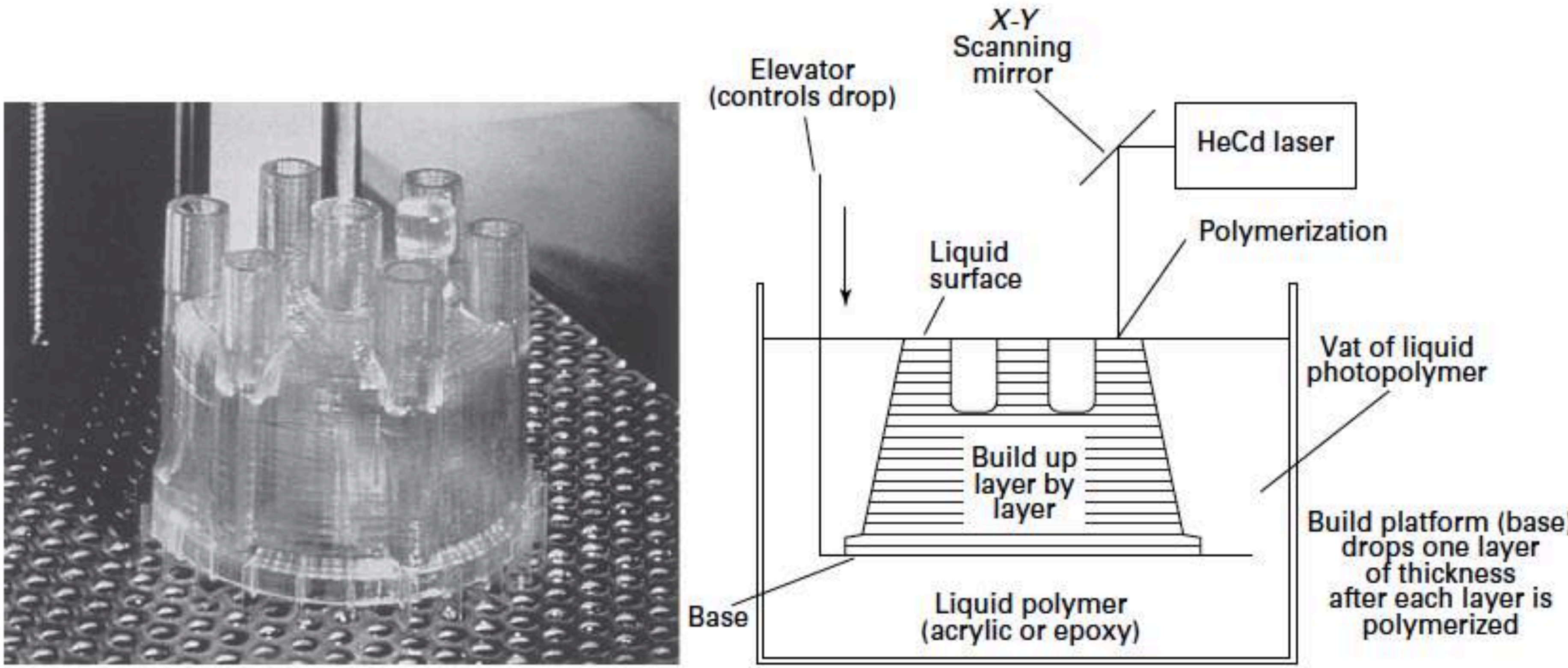


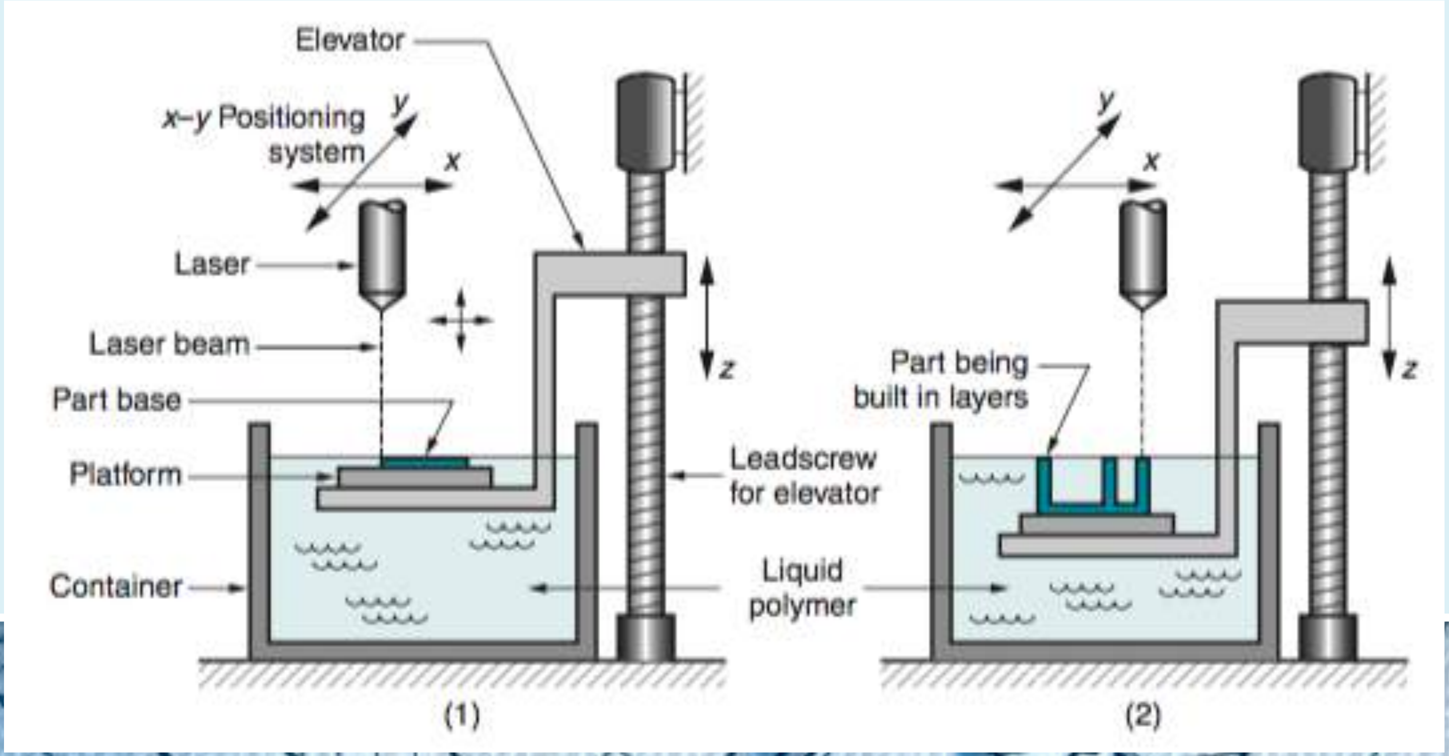
FIGURE 19-2 The stereolithography apparatus (SLA) (right) can build a part (b) in plastic layer-by-layer, using a laser to polymerize liquid photopolymer. *(*Cutting Tool Engineering*, December 1989. Reprinted with Permission.)*

Additive Manufacturing Processes

- LIQUID-BASED PROCESSES
  - STEREOLITHOGRAPHY
  - SOLID GROUND CURING
  - INKJET DEPOSITION OR DROPLET DEPOSITION
- POWDER-BASED PROCESSES
  - SELECTIVE LASER SINTERING (SLS) AND SELECTIVE LASER MELTING SLM
  - ELECTRON BEAM MELTING (EBM)
  - THREE-DIMENSIONAL PRINTING
  - SINTERMASK
- DEPOSITION-BASED PROCESSES
  - FUSED DEPOSITION MODELING (FDM)
  - LASER-ENGINEERED NET SHAPING (LENS) AND DIRECT METAL DEPOSITION (DMD)
  - LAMINATED-OBJECT MANUFACTURING (LOM)

STEREOLITHOGRAPHY APPARATUS (SLA)

- Stereolithography (SL) is a layered rapid prototyping process in which an ultraviolet laser is used to selectively cure a vat of liquid photopolymer resin in order to fabricate a part from a CAD model;



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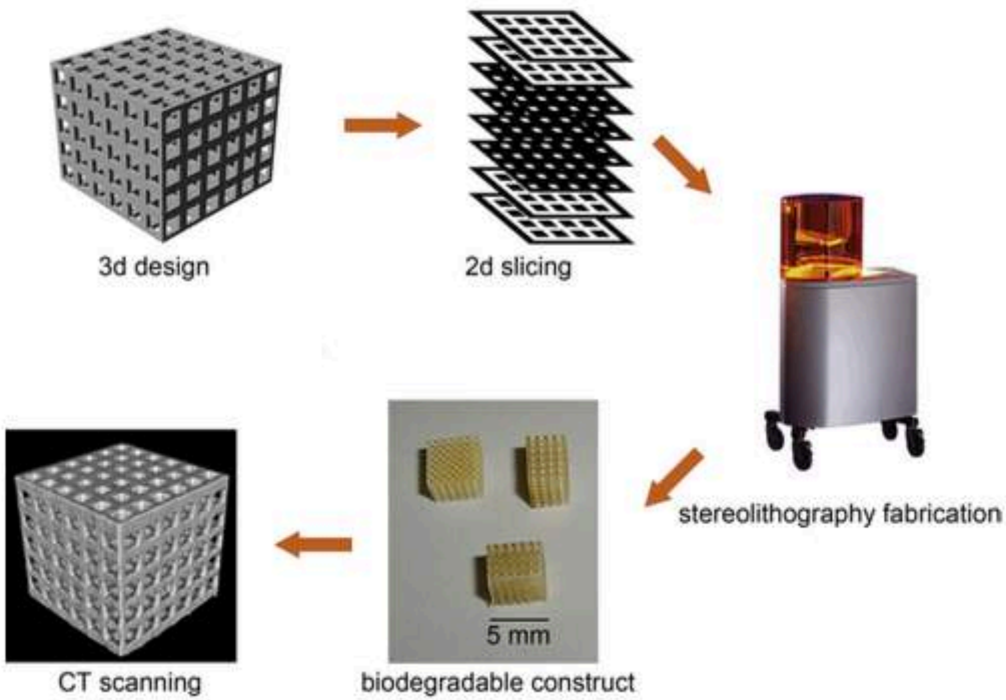

Fig. 2. Overview of the processes involved in the design and fabrication of structures by stereolithography.

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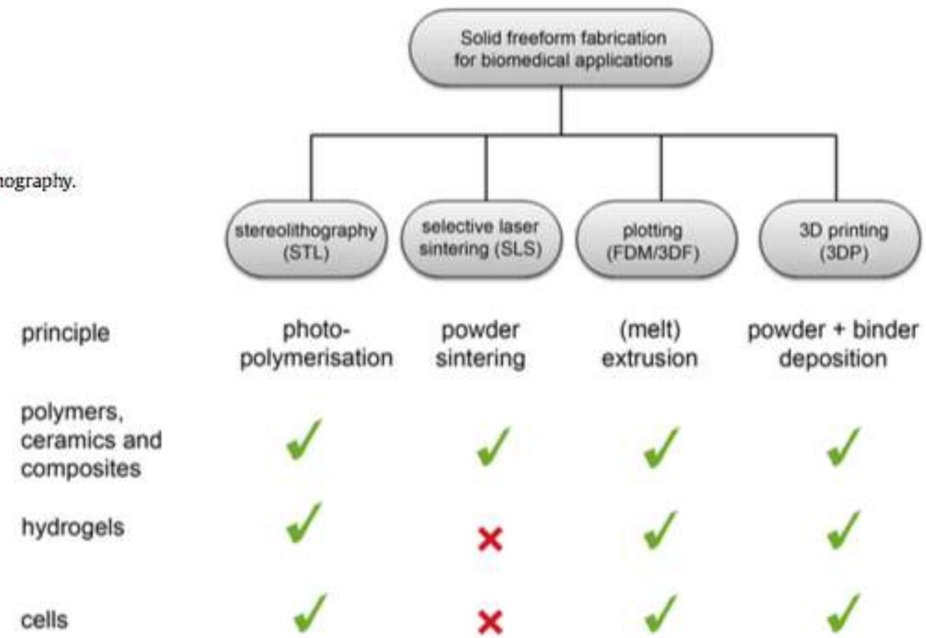


SOLID GROUND CURING (SGC)

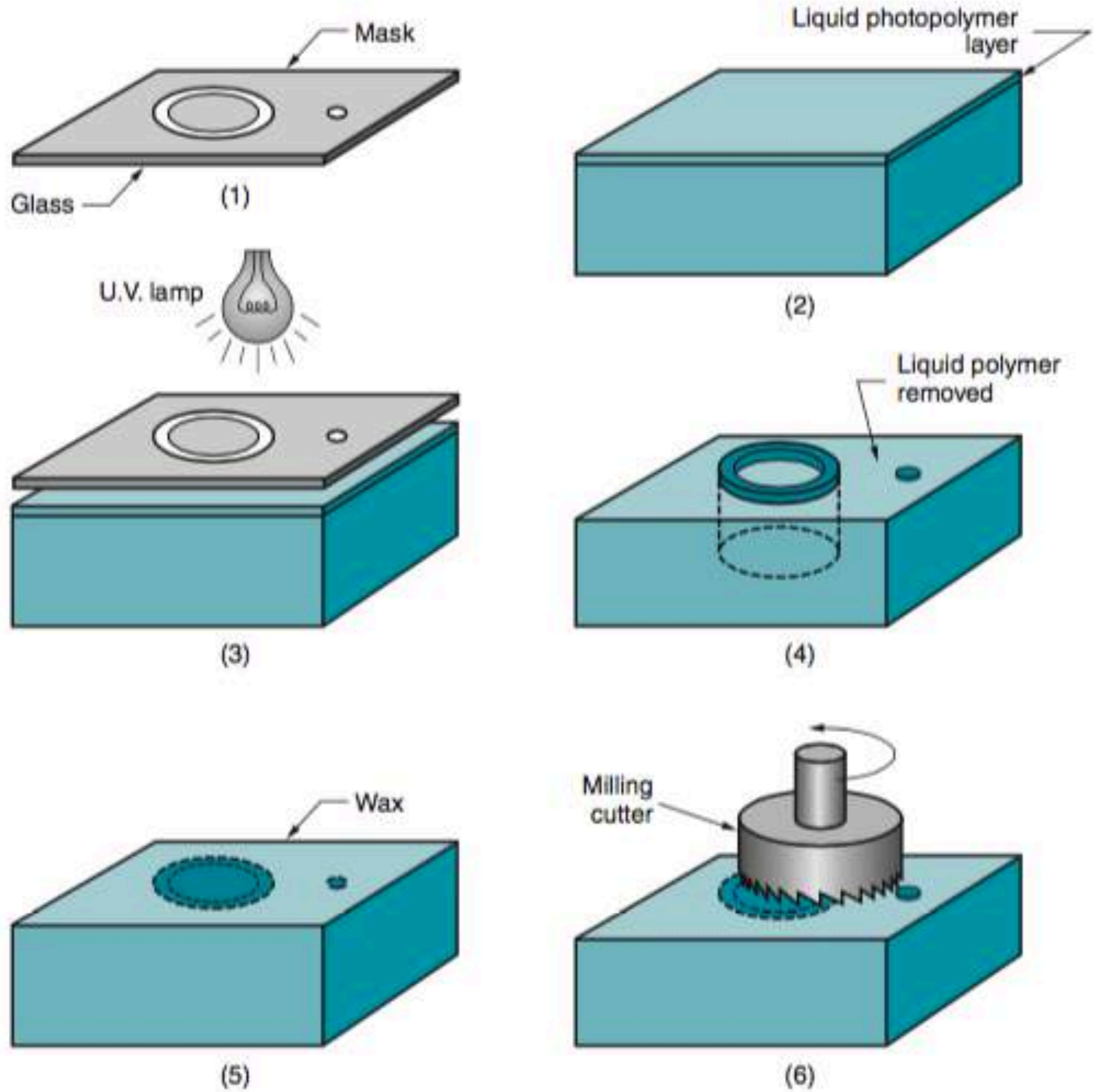


FIGURE 26.3 Solid ground curing process for each layer: (1) mask preparation, (2) applying liquid photopolymer layer, (3) mask positioning and exposure of layer, (4) uncured polymer removed from surface, (5) wax filling, (6) milling for flatness and thickness. (Credit: *Fundamentals of Modern Manufacturing*, 4th Edition by Mikell P. Groover, 2010. Reprinted with permission of John Wiley & Sons, Inc.)

SOLID GROUND CURING (SGC)

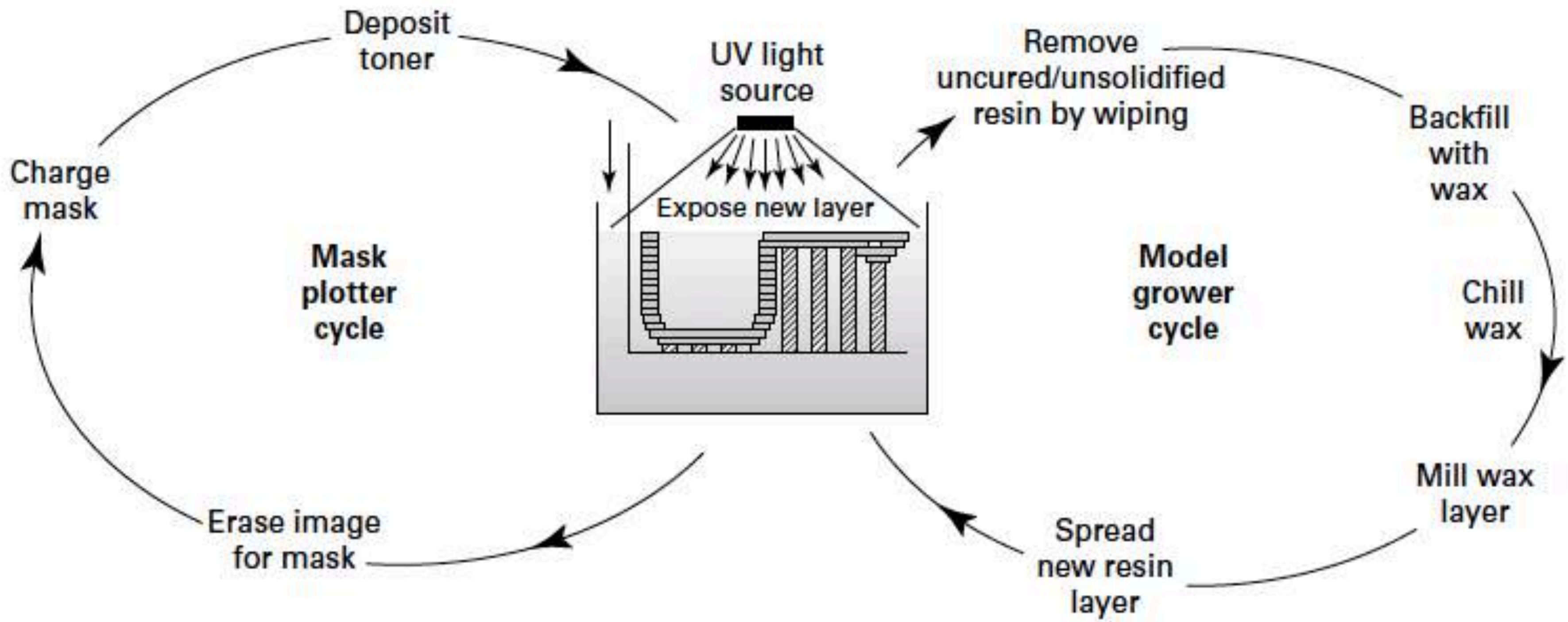
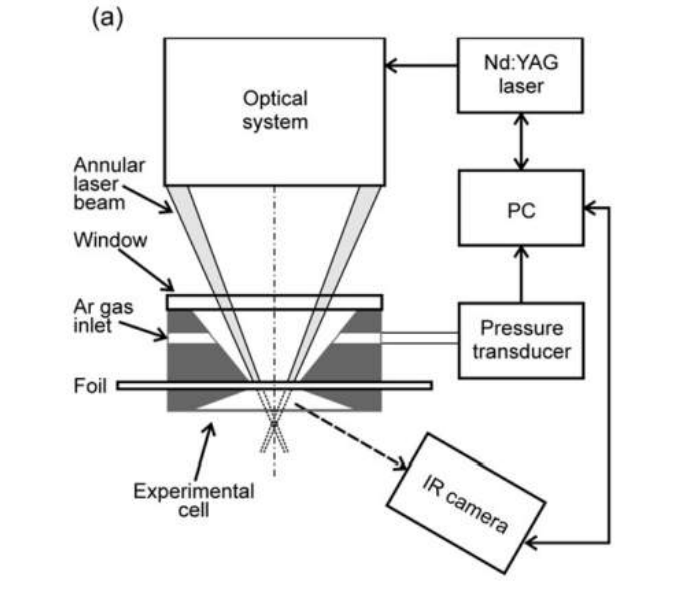


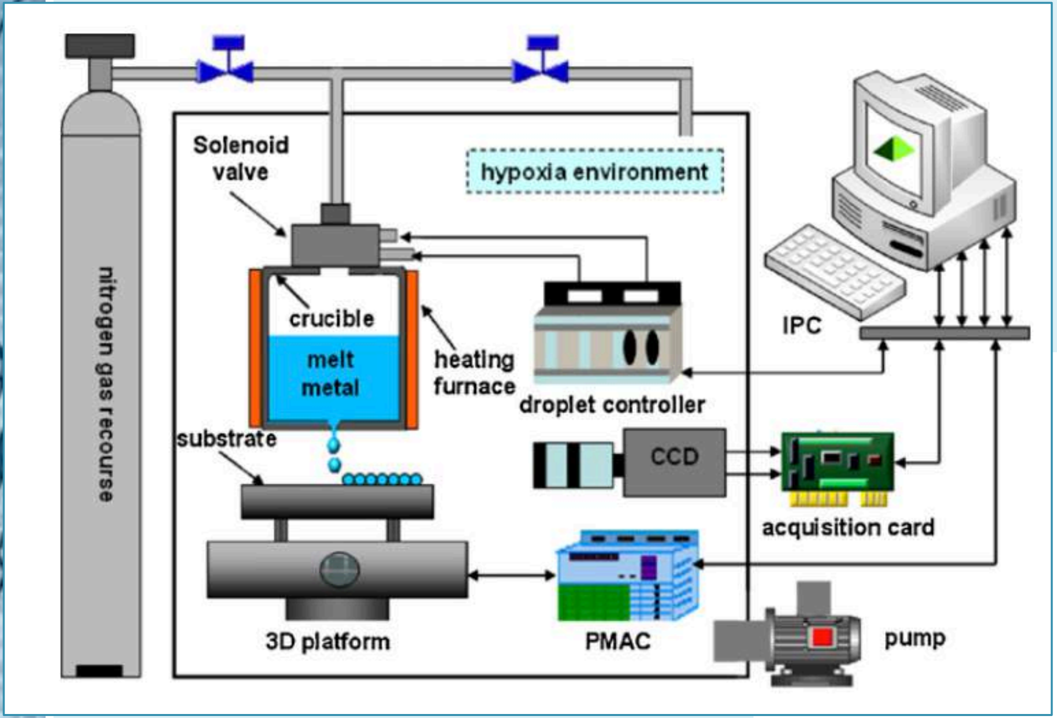
FIGURE 19-9 The solid ground curing process simultaneously operates a mask plotter cycle to produce the layer masks and a model grower cycle to deposit the layers.

INKJET DEPOSITION (ID) OR DROPLET DEPOSITION MANUFACTURING (DDM)

Can be split into two categories

- Drop on drop
- Continuous droplet





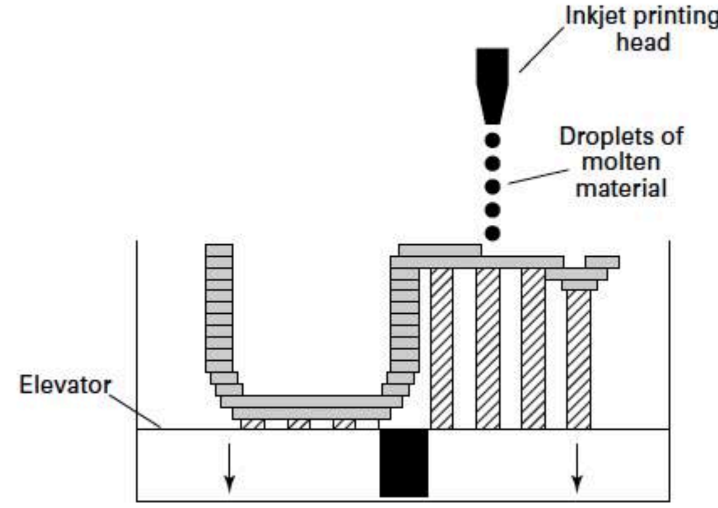


FIGURE 19-10 Inkjet deposition uses the ballistic particle concept to build solid objects.

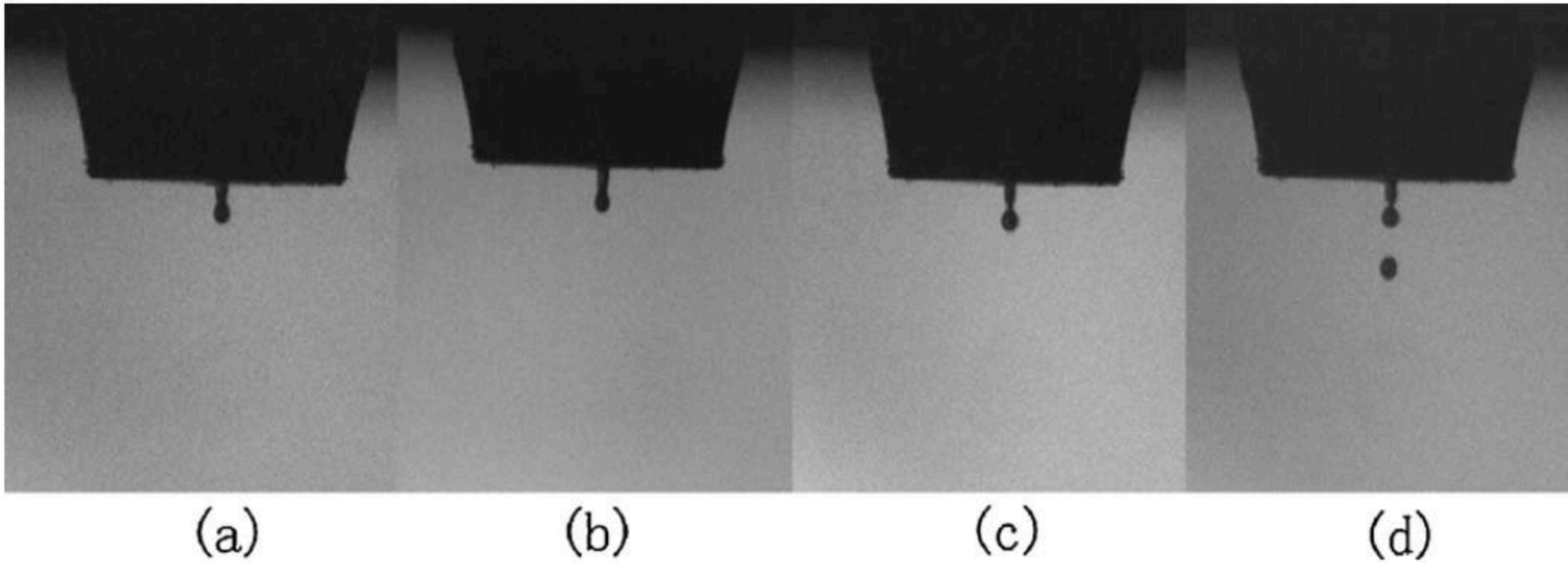


Fig. 3. Photograph of single droplet sprayed from a 150 μm diameter nozzle: (a) $t = 0$ ms; (b) $t = 0.2$ ms; (c) $t = 0.4$ ms; and (d) $t = 0.6$ m

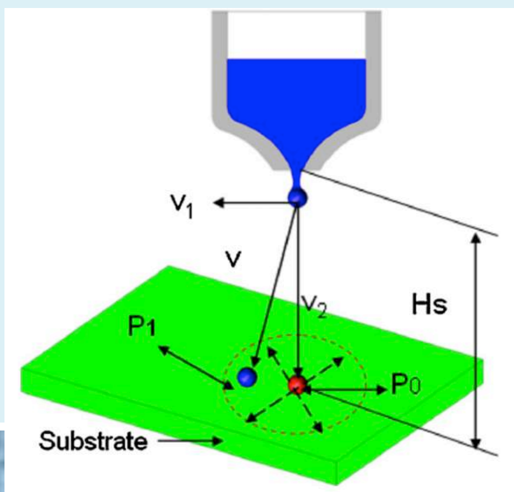


Fig. 6. The schematic diagram of droplet deposition error in position.

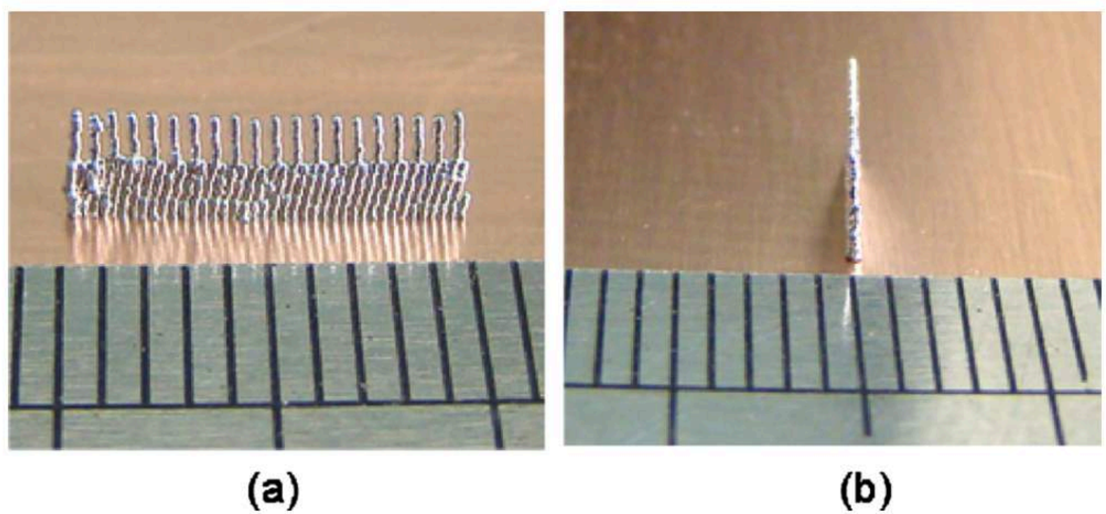


Fig. 9. The deposited sample under deposition distance 20 mm: (a) front view and (b) left view.

SELECTIVE LASER SINTERING (SLS) AND SELECTIVE LASER MELTING (SLM)

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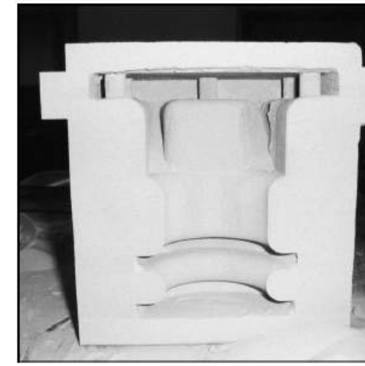


FIGURE 19-12 Half of a silica sand castin mold produced by selective laser sintering. *(Courtesy of Mr. C. S. Huskamp, St. Louis, MC*

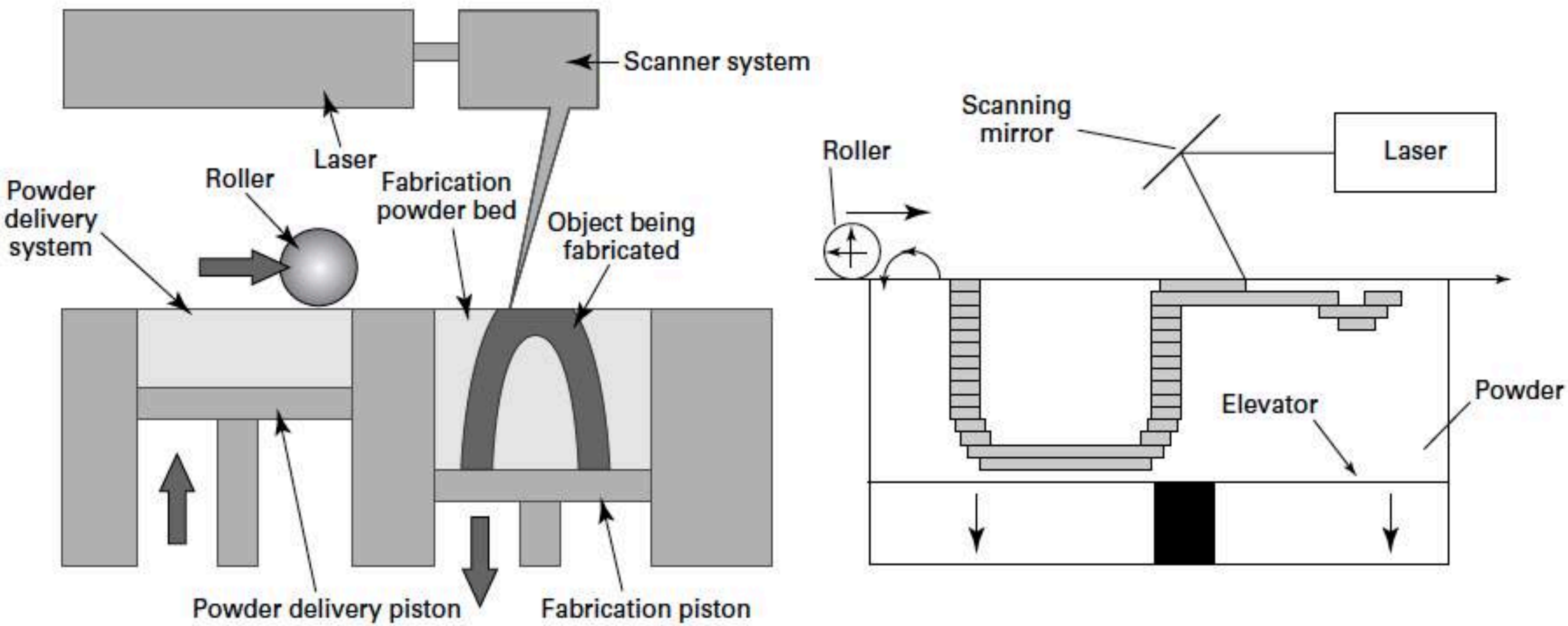


FIGURE 19-11 Selective laser sintering uses a laser to scan and sinter powdered material into solid shapes in a layer-by-layer manner.

ELECTRON BEAM MELTING (EBM)

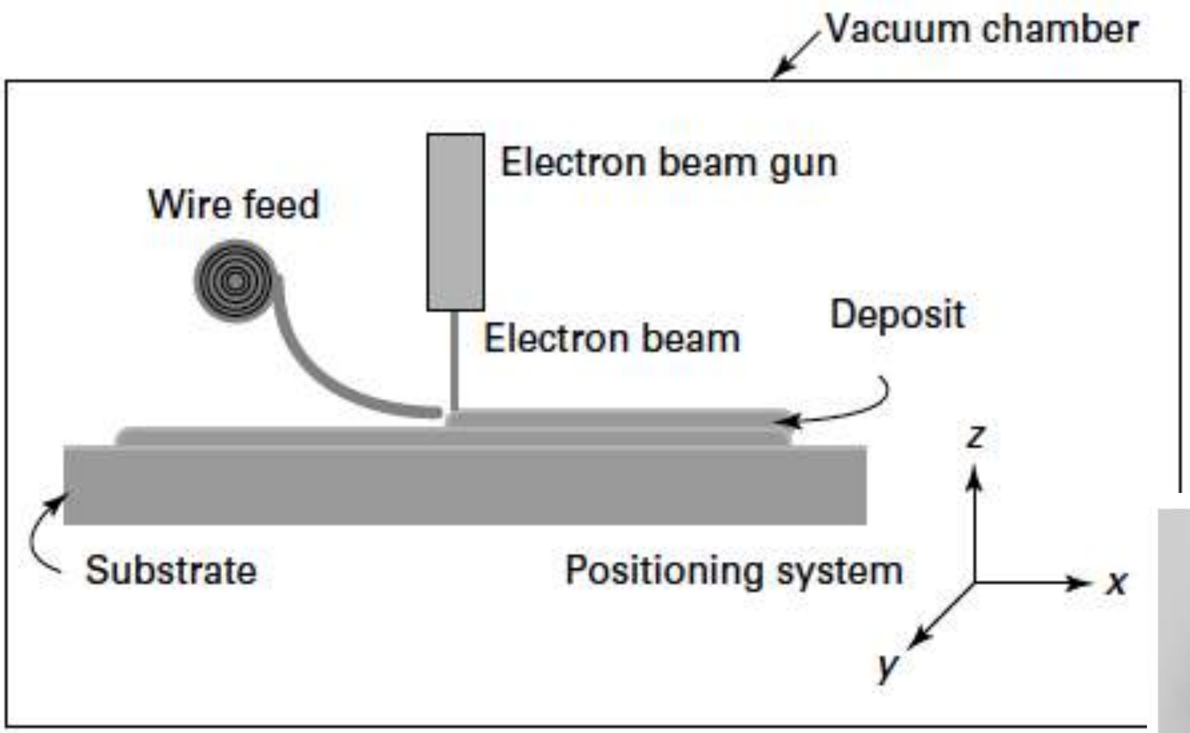


FIGURE 19-14 Schematic of the electron beam manufacturing process.

FIGURE 19-15 Small metal impeller made from titaniu (Ti-6Al-4V). *(Arcam AB)*

THREE-DIMENSIONAL PRINTING

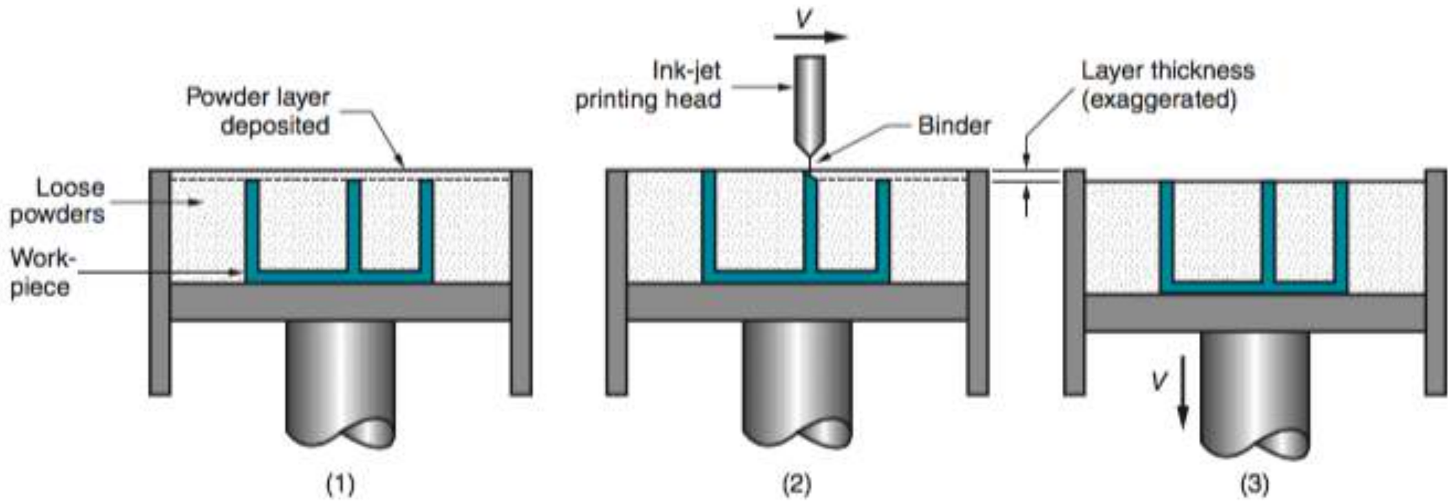


FIGURE 26.5 Three-dimensional printing: (1) powder layer is deposited, (2) ink-jet printing of areas that will become the part, and (3) piston is lowered for next layer (key: v = motion). (Credit: *Fundamentals of Modern Manufacturing*, 4th Edition by Mikell P. Groover, 2010. Reprinted with permission of John Wiley & Sons, Inc.)

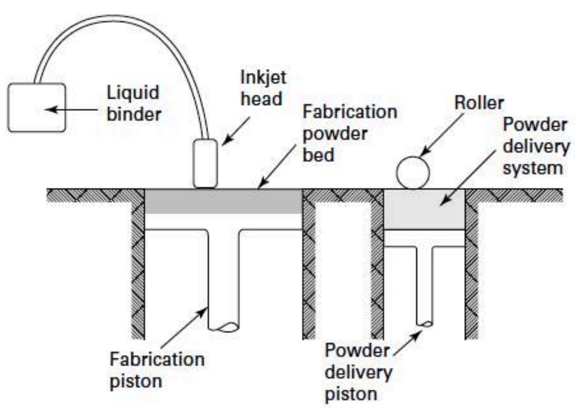
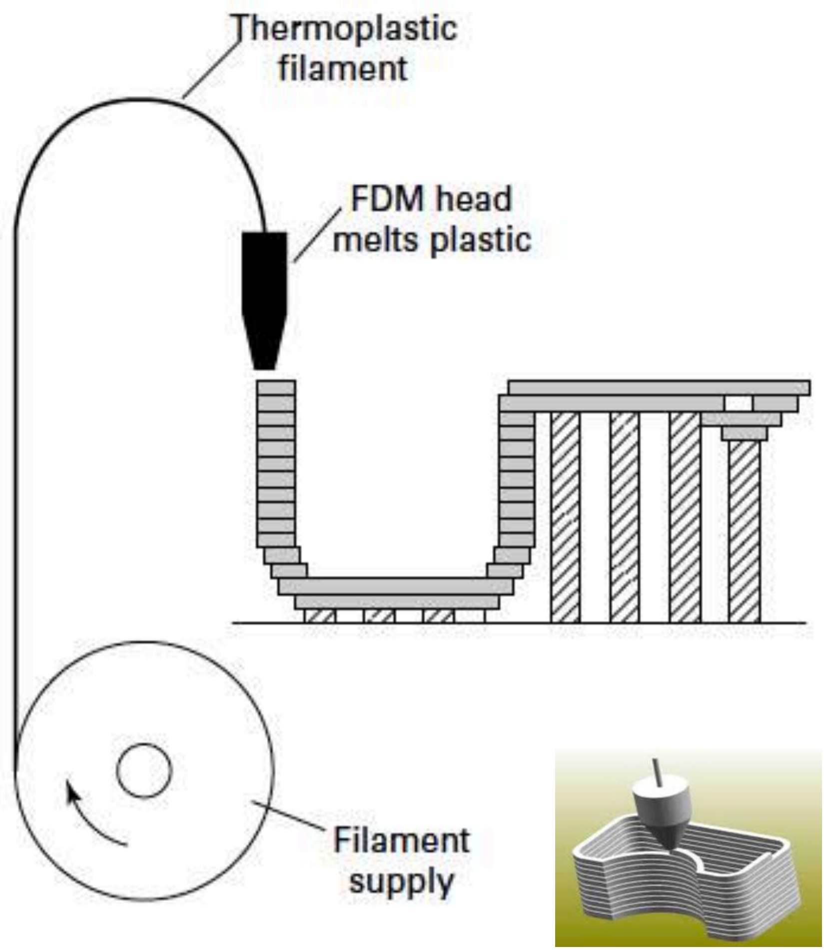
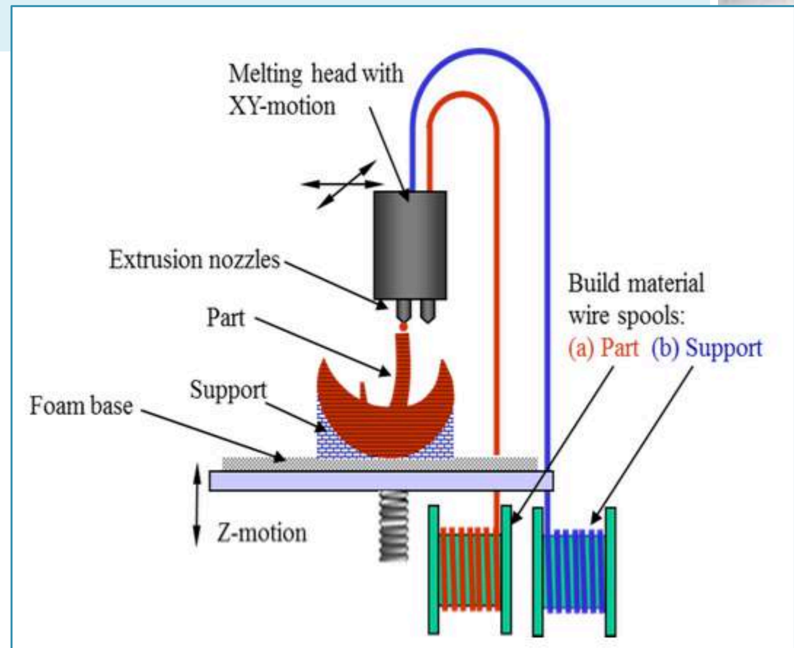


FIGURE 19-16 Three-dimensional printing builds components by selectively binding powdered material in a layer-by-layer manner. Metal parts are then sintered and possibly infiltrated to produce strong, high-density products.

FUSED DEPOSITION MODELING (FDM)





The most common non-wax material used in FDM is Acrylonitril Butadiene Styrene (ABS). Like wax, this material can be used fo making investment casting patterns. This material has some advantage over the wax [3] and this material is proven to be suitable for burn ou from the ceramic shell with minimal modification to the standar foundry processes. Therefore, the FDM machine can be used fo making complex casting patterns to be used in investment casting [4] In investment casting with ABS, either wax gates or vents are attache to the ABS pattern by the foundry or these are made as integral part o pattern during pattern making by FDM.

LAMINATED-OBJECT MANUFACTURING (LOM)

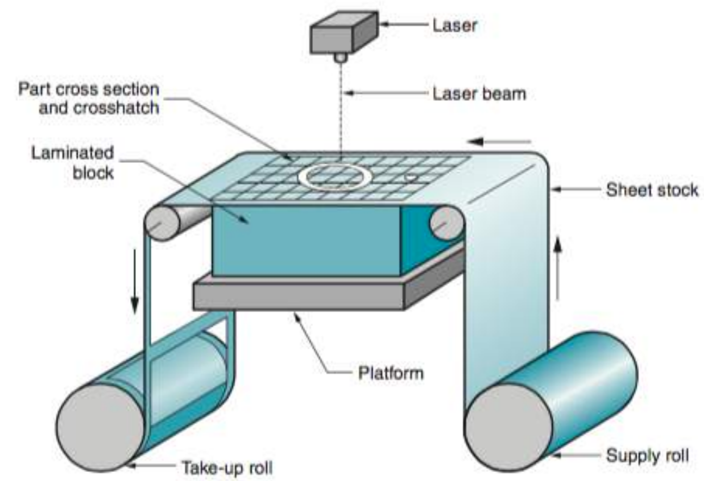


FIGURE 26.4
Laminated-object manufacturing. (Credit: *Fundamentals of Modern Manufacturing*, 4th Edition by Mikell P. Groover, 2010. Reprinted with permission of John Wiley & Sons, Inc.)

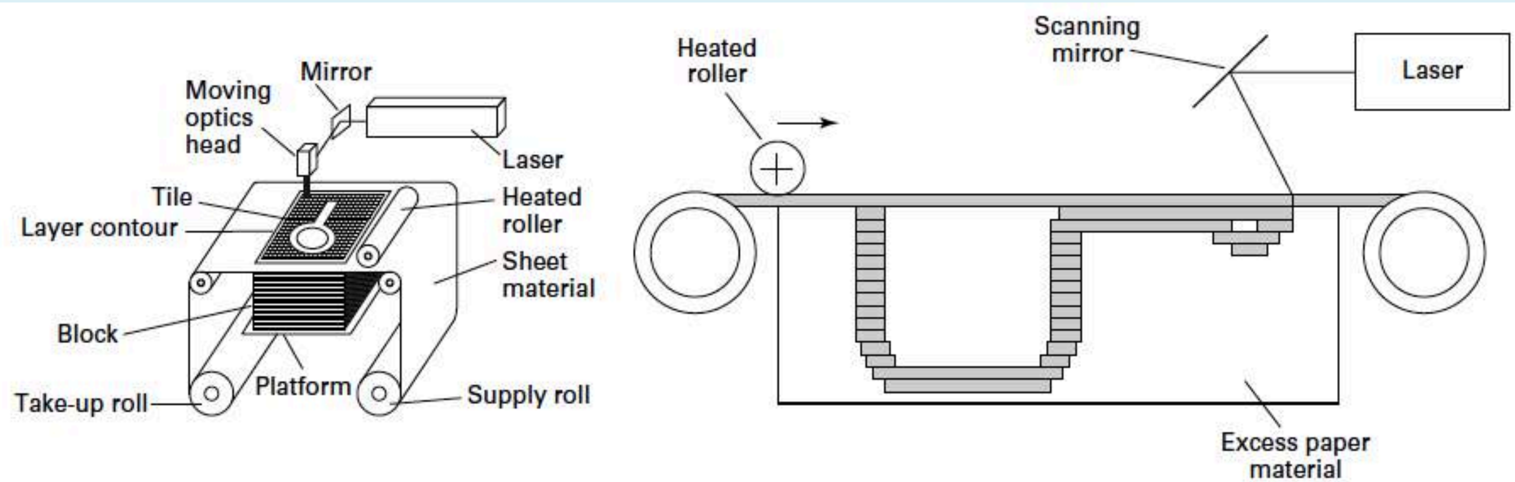


FIGURE 19-19 Schematic of the laminated object manufacturing process where solid sheets are used to create the layers.

TABLE 19-1 Comparison of Additive Processes

Process	Starting Material	Layering Mechanism	Possible Materials
Stereolithography (SLA)	Liquid photopolymer	Polymer curing by UV light	Photopolymers
Inkjet deposition (ID)	Molten liquid	Solidification of droplets	Thermoplastic polymers, waxes, low melting point metals
Selective laser sintering (SLS)	Powders	Sintering or melting	Thermoplastic polymers, waxes, metals, binder coated sands
Electron beam melting (EBM)	Powders	Melting	Metals (titanium, tool steels, superalloys)
Three-dimensional printing	Powders	Deposited molten binder	Metals, ceramics, polymers, cermets, sand
Fused deposition modeling (FDM)	Semi-liquid polymer	Solidification of extruded strand	Thermoplastic polymers
Laminated-object manufacturing (LOM)	Solid sheets	Fusing of sheet material	Paper, polymers, ceramic

Biomedical production of implants by additive electro-chemical and physical processes

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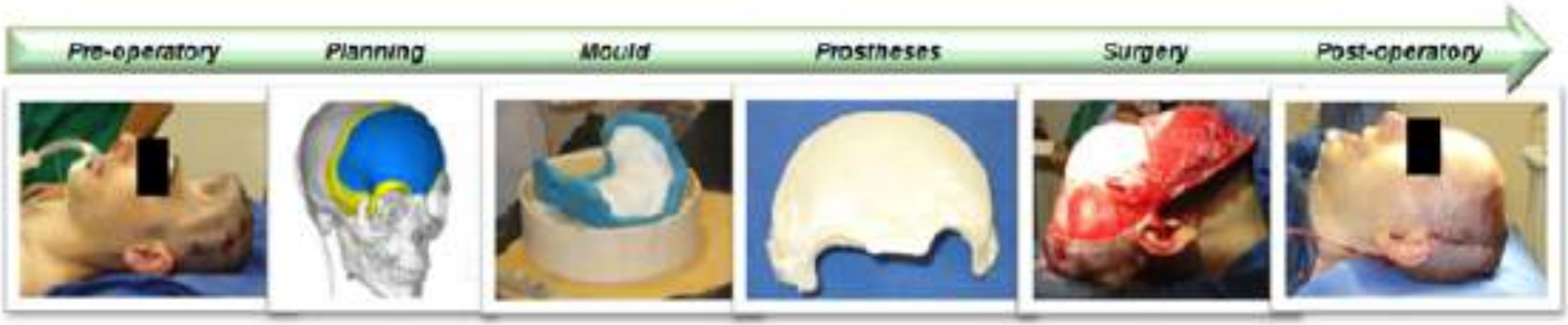

Fig. 6. Cranial reconstruction of the front-temporo-parietal area developed at CTI in cooperation with the Sobrapar Hospital (Brazil).

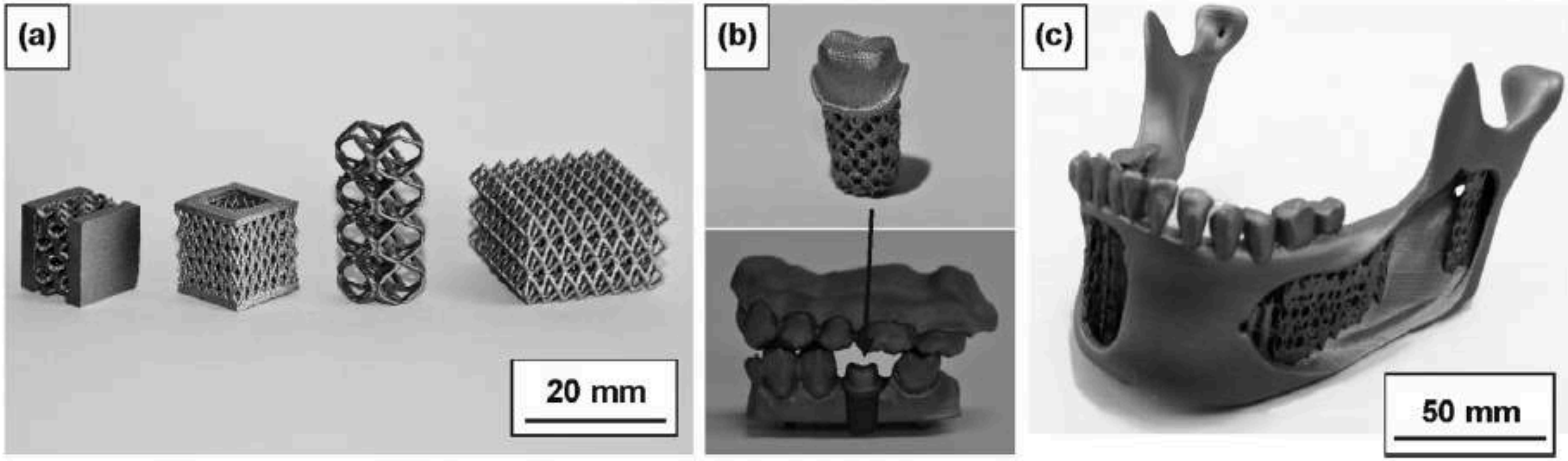

FIGURE 19-22 Titanium skull patch produced by the electron beam melting process beginning with data obtained from a CT scan of an injured person. This is an example of a one-of-a-kind, or custom, product. *(Arcam AB)*

Global Engineering

- Answers for questions Class #2 +
- How easy if to biult your prototype in 3D printing?
- How much does it costs a simple machine?
- How does it costs to buy the raw material?
- Mechanical Resistence? Shapes? Maximum size? Resolution?

HW #5 – Manufacturing of Polymer Prototypes in 3D printing - 09 sept