RAPID PROTOTYPING

Learning Objectives:

By the end of the lecture the student should be able to:

- Explain the fundamentals of Rapid Prototyping
- Outline and explain differences of Rapid Prototyping Technologies
- Provide applications and benefits of Rapid Prototyping

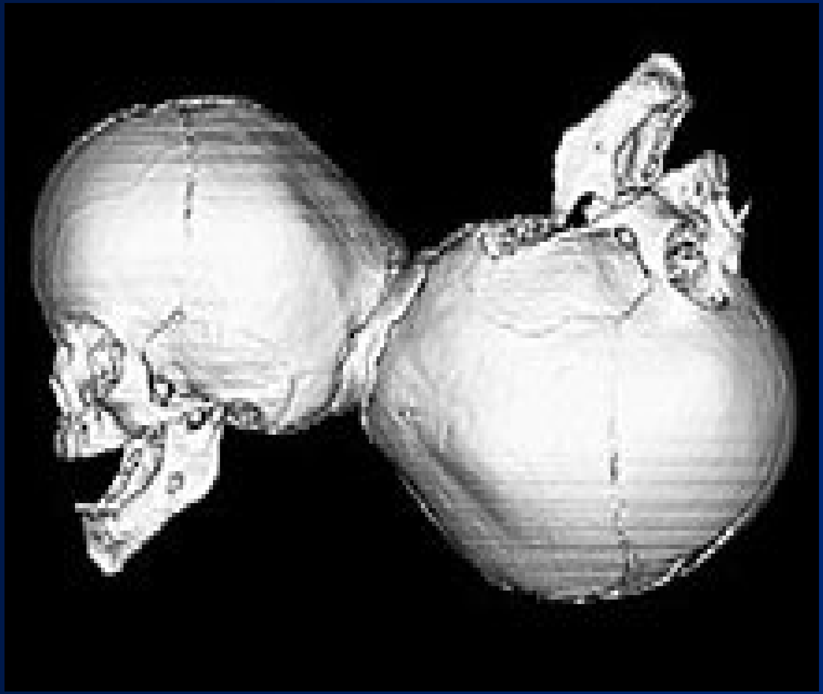
Courtesy of Dr. Chen, Northern Illinois University

Help for Testing

Art Sculptures

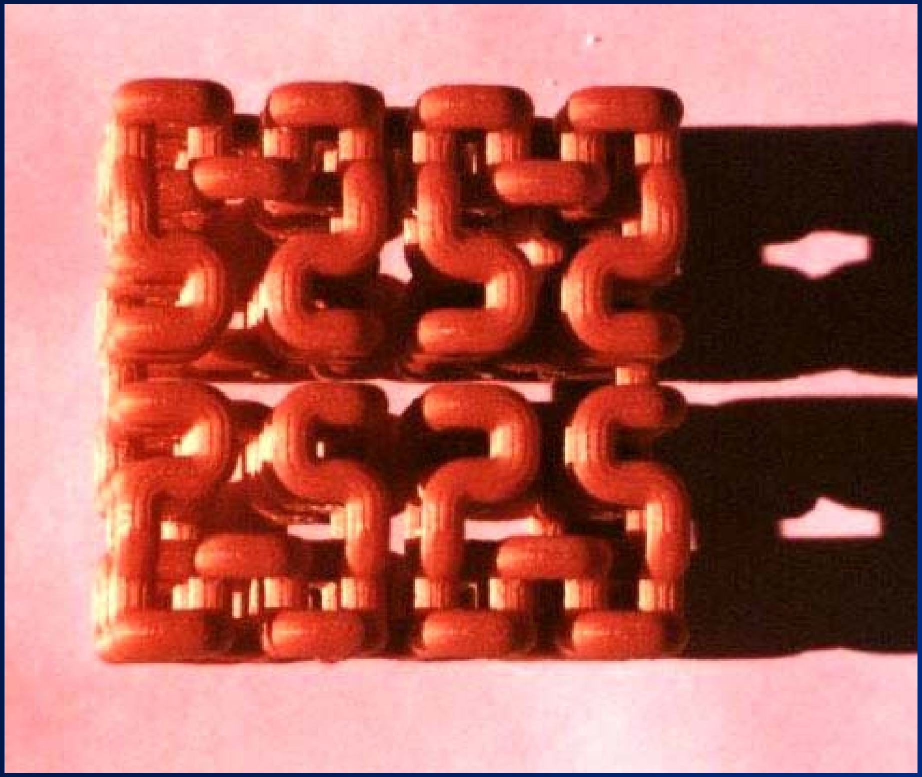
Medical Models

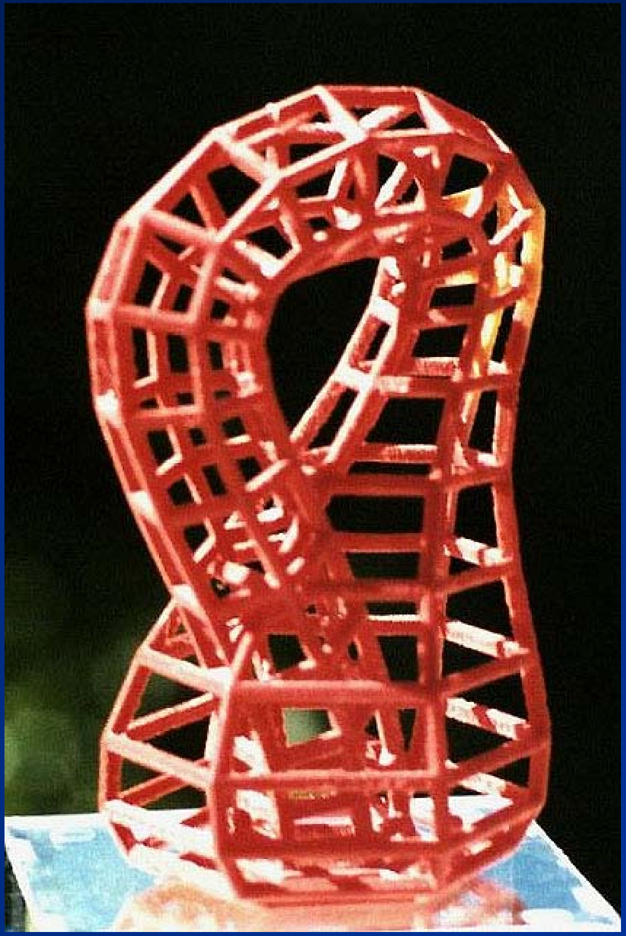
Medical Models (Conjoined Twins)



Architectural Models

Mathematical Models





Rapid Prototyping (RP)

A family of unique fabrication processes developed to make engineering prototypes in minimum lead time based on a CAD model of the item

- The traditional method is machining
  - Machining can require significant lead-times – several weeks, depending on part complexity and difficulty in ordering materials
- RP allows a part to be made in hours or days given that a computer model of the part has been generated on a CAD system
- **WYSIWYG** - ***What You See Is What You Get***

Why Rapid Prototyping?

- Because product designers would like to have a physical model of a new part or product design rather than just a computer model or line drawing
  - Creating a prototype is an integral step in design
  - A *virtual prototype* (a computer model of the part design on a CAD system) may not be sufficient for the designer to visualize the part adequately
  - Using RP to make the prototype, the designer can visually examine and physically feel the part and assess its merits and shortcomings

Rapid Prototyping Technologies – Two Basic Categories:

1. *Material removal RP* - machining, primarily milling and drilling, using a dedicated CNC machine that is available to the design department on short notice
   - Starting material is often wax, which is easy to machine and can be melted and re-solidified
   - The CNC machines are often small
   - Called *desktop milling* or *desktop machining*
2. *Material addition RP* - adds layers of material one at a time to build the solid part from bottom to top

Starting Materials in Material Addition RP

1. Liquid(s) that are cured layer by layer into solid
2. Powder(s) that are aggregated and bonded layer by layer to form a solid
3. Solid sheets or filaments that are laminated to create the solid part

Addition RP Methods

- In addition to starting material, the various material addition RP technologies use different methods of building and adding layers to create the solid part
  - There is a correlation between starting material and part building techniques

Steps to Prepare Control Instructions

1. *Geometric modeling* - modeling the component on a CAD system to define its enclosed volume.
2. *Tessellation of the geometric model* - the CAD model is converted into a computerized format that approximates its surfaces by facets (triangles or polygons) – STL file format.
3. *Slicing of the model into layers* - the model in computerized format is sliced into closely-spaced parallel horizontal layers.

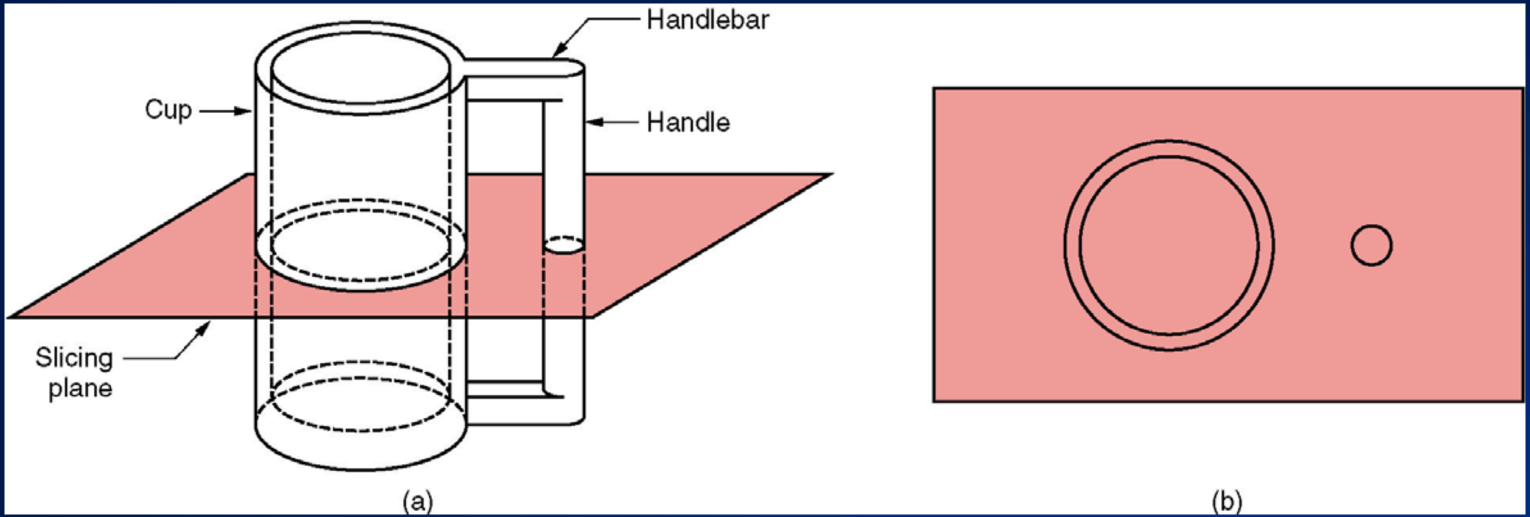


Figure 1 - Conversion of a solid model of an object into layers (only one layer is shown)

Alternative Names for Rapid Prototyping

- *Layer manufacturing*
- *Direct CAD manufacturing*
- *Solid freeform fabrication*
- *Rapid prototyping and manufacturing* (RPM)
  - Indicates that RP technologies are being used increasingly to make production parts and production tooling, not just prototypes

Classification of Rapid Prototyping Technologies

- There are various ways to classify the RP techniques that have currently been developed
- The RP classification used here is based on the form of the starting material:

1. Liquid-based
2. Solid-based
3. Powder-based

Liquid-Based Rapid Prototyping Systems

- Starting material is a liquid
- About a dozen RP technologies are in this category
- The following are described here:
  - Stereolithography
  - Solid ground curing
  - Droplet deposition manufacturing

Stereolithography (STL/SLA)

RP process for fabricating a solid plastic part out of a photosensitive liquid polymer using a directed laser beam to solidify the polymer

- Part fabrication is accomplished as a series of layers, in which one layer is added onto the previous layer to gradually build the desired 3-D geometry
- The first addition RP technology - introduced 1988 by 3D Systems Inc. based on the work of Charles Hull
- More installations of STL than any other RP method

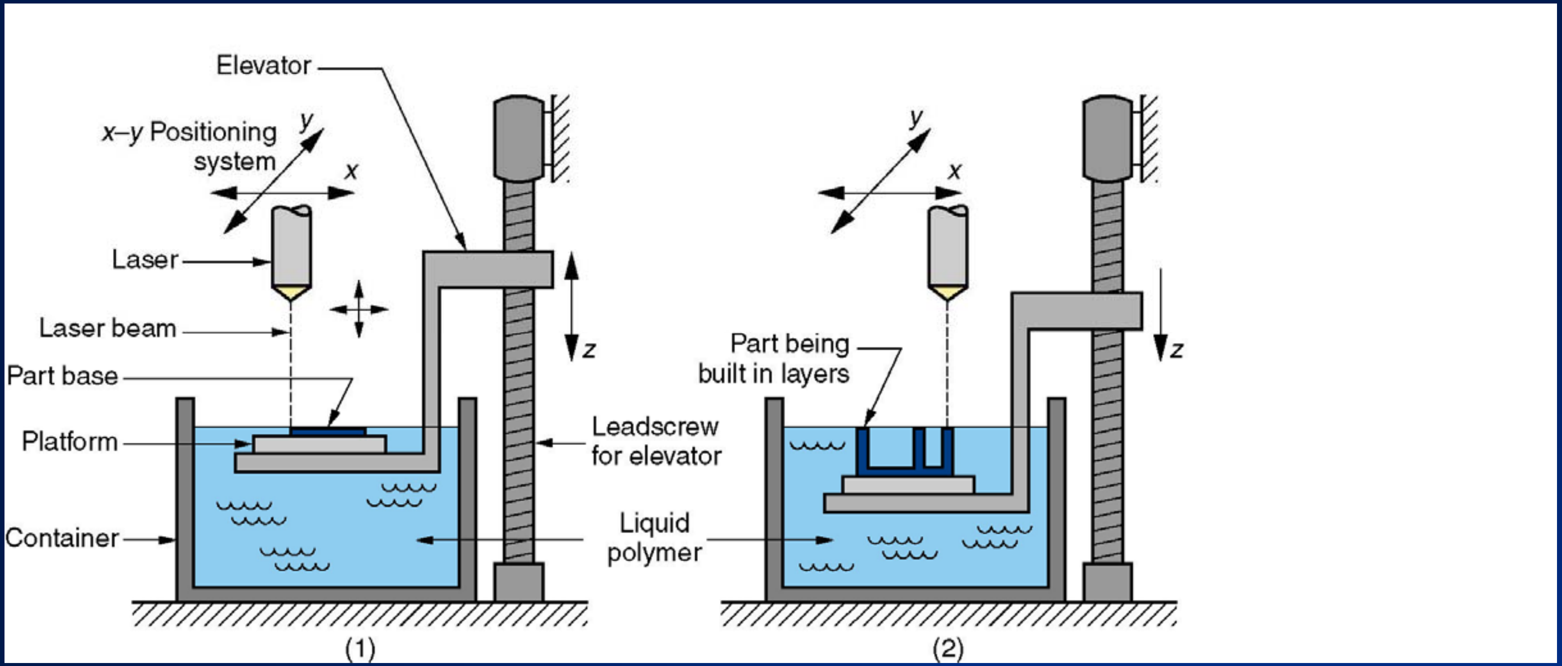


Figure 2 - Stereolithography: (1) at the start of the process, in which the initial layer is added to the platform; and (2) after several layers have been added so that the part geometry gradually takes form

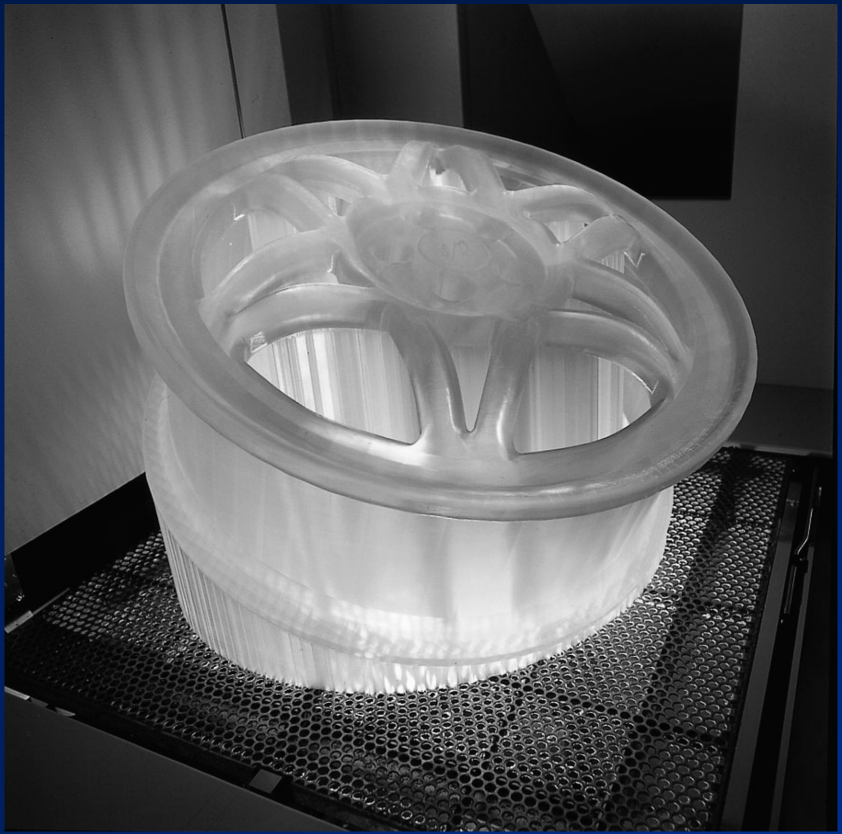


Figure 3 - A part produced by stereolithography

(photo courtesy of 3D Systems, Inc.)

Some Facts about STL

- Each layer is 0.076 mm to 0.50 mm (0.003 in to 0.020 in.) thick
  - Thinner layers provide better resolution and more intricate shapes; but processing time is longer
- The starting materials are liquid monomers
- Polymerization occurs upon exposure to UV light produced by helium-cadmium or argon ion lasers
  - Laser scan speeds typically 500 to 2500 mm/s

Solid Ground Curing (SGC)

Like stereolithography, SGC works by curing a photosensitive polymer layer by layer to create a solid model based on CAD geometric data

- Instead of using a scanning laser beam to cure a given layer, the entire layer is exposed to a UV source through a mask above the liquid polymer
- Hardening takes 2 to 3 s for each layer

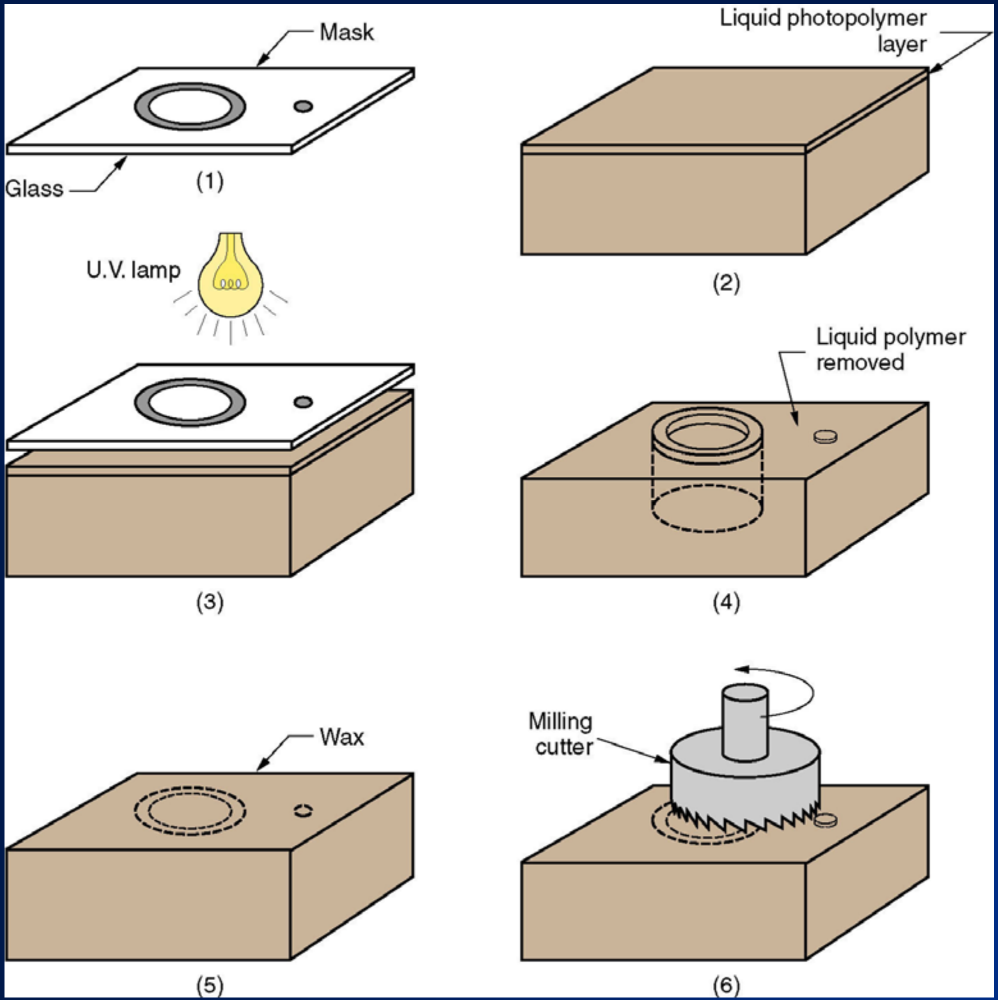


Figure 4 - SGC steps for each layer:

(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

Facts about SGC

- The sequence for each layer takes about 90 seconds
- Time to produce a part by SGC is claimed to be about eight times faster than other RP systems
- The solid cubic form created in SGC consists of solid polymer and wax

Droplet Deposition Manufacturing (DDM)

The starting material is melted and small droplets are shot by a nozzle onto a previously formed layer

- Droplets cold weld to surface to form a new layer
- Deposition for each layer controlled by a moving x-y spray nozzle whose path is based on a cross-section of a CAD geometric model that is sliced into layers
- After each layer is applied, the platform supporting the part is lowered a distance = to the layer thickness
- Work materials used in DDM include wax and thermoplastics

Solid-Based Rapid Prototyping Systems

- Starting material is a solid
- Two solid-based RP systems are presented here:
  - Laminated object manufacturing
  - Fused deposition modeling

Laminated Object Manufacturing (LOM)

A solid physical model is made by stacking layers of sheet stock, each an outline of the cross-sectional shape of a CAD model that is sliced into layers

- Starting material = sheet stock, such as paper, plastic, cellulose, metals, or fiber-reinforced materials
- The sheet material is usually supplied with adhesive backing as rolls that are spooled between two reels
- After cutting, excess material in the layer remains in place to support the part during building

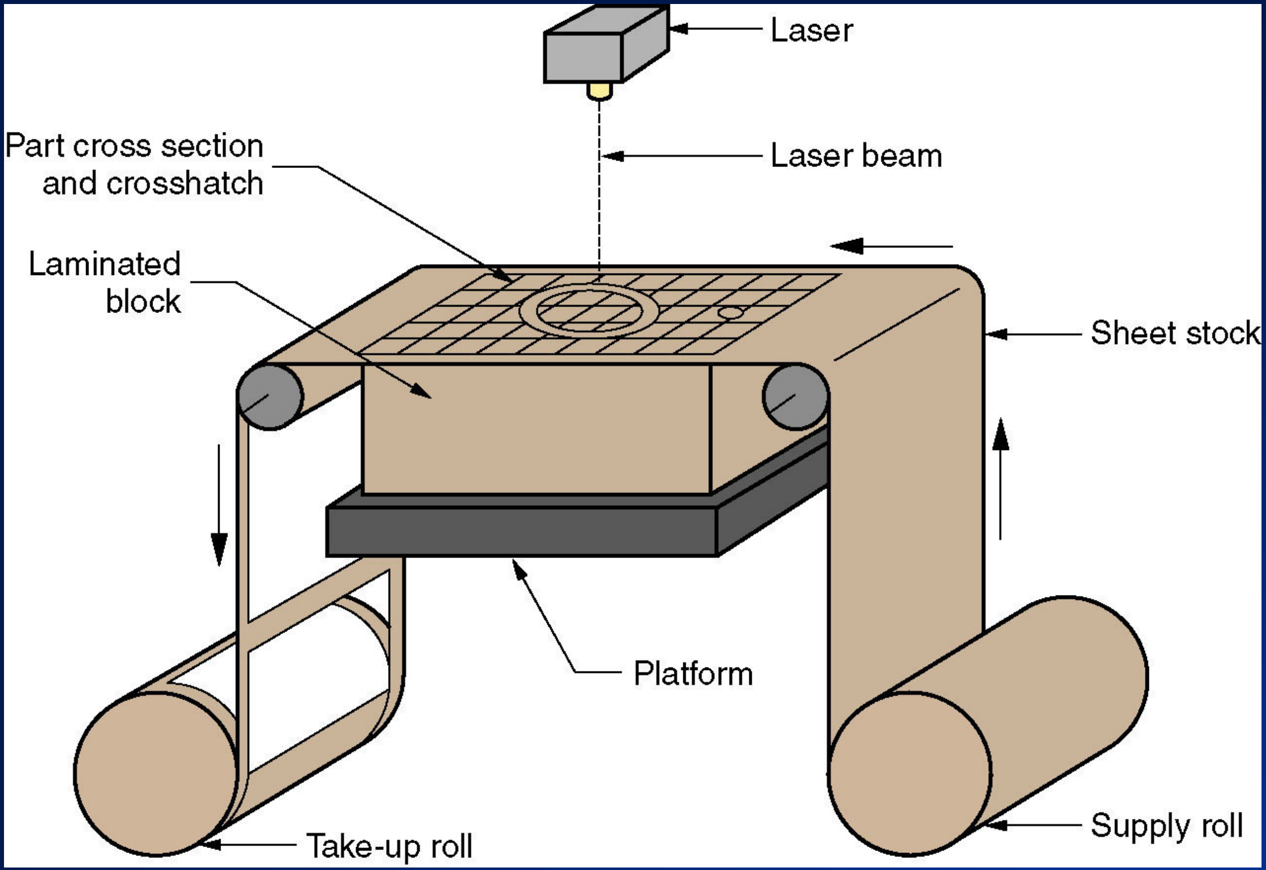


Figure 5 - Laminated object manufacturing

Fused Deposition Modeling (FDM)

RP process in which a long filament of wax or polymer is extruded onto the existing part surface from a workhead to complete each new layer

- The workhead is controlled in the *x-y* plane during each layer and then moves up by a distance equal to one layer in the *z*-direction
- The extrudate is solidified and cold welded to the cooler part surface in about 0.1 s
- Part is fabricated from the base up, using a layer-by-layer procedure

Powder-Based Rapid Prototyping Systems

- Starting material is a powder
- Two RP systems are described here:
  - Selective laser sintering
  - Three dimensional printing

Selective Laser Sintering (SLS)

A moving laser beam sinters heat-fusible powders in areas corresponding to the CAD geometry model one layer at a time to build the solid part

- After each layer is completed, a new layer of loose powders is spread across the surface
- Layer by layer, the powders are gradually bonded into a solid mass that forms the 3-D part geometry
- In areas not sintered by the laser beam, the powders are loose and can be poured out of completed part

Three Dimensional Printing (3DP)

In 3DP, the part is built in layer-by-layer fashion using an ink-jet printer to eject adhesive bonding material onto successive layers of powders

- The binder is deposited in areas corresponding to the cross-sections of the solid part, as determined by slicing the CAD geometric model into layers
- The binder holds the powders together to form the solid part, while the unbonded powders remain loose to be removed later
- To further strengthen the part, a sintering step can be applied to bond the individual powders

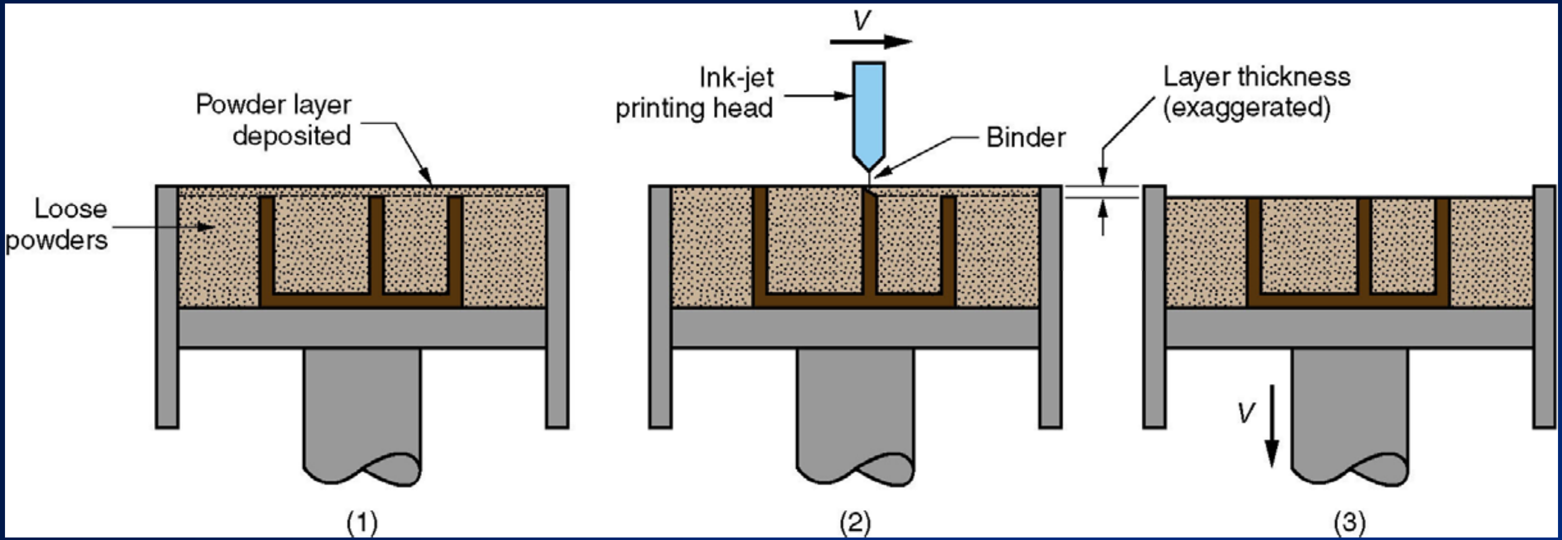


Figure 6 - Three dimensional printing: (1) powder layer is deposited, (2) ink-jet printing of areas that will become the part, and (3) piston is lowered for next layer (key: *v* = motion)

RP Applications

- Applications of rapid prototyping can be classified into three categories:
  1. Design
  2. Engineering analysis and planning
  3. Tooling and manufacturing

RP Applications: Design

- Designers are able to confirm their design by building a real physical model in minimum time using RP
- Design benefits :
  - Reduced lead times to produce prototype components
  - Improved ability to visualize part geometry
  - Early detection and reduction of design errors
  - Increased capability to compute mass properties

RP Applications: Engineering Analysis and Planning

- Existence of part allows certain engineering analysis and planning activities to be accomplished that would be more difficult without the physical entity
  - Comparison of different shapes and styles to determine aesthetic appeal
  - Wind tunnel testing of different streamline shapes
  - Stress analysis of a physical model
  - Fabrication of pre-production parts for process planning and tool design

RP Applications: Tooling

- Called *rapid tool making* (RTM) when RP is used to fabricate production tooling

RP Applications: Manufacturing

- Small batches of plastic parts that could not be economically injection molded because of the high mold cost
- Parts with complex internal geometries that could not be made using conventional technologies without assembly
- One-of-a-kind parts such as bone replacements that must be made to correct size for each user

Problems with Rapid Prototyping

- Part accuracy:
  - Staircase appearance for a sloping part surface due to layering
  - Shrinkage and distortion of RP parts
- Limited variety of materials in RP
  - Mechanical performance of the fabricated parts is limited by the materials that must be used in the RP process