Reverse Engineering & Rapid Prototyping

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Lecture No 1

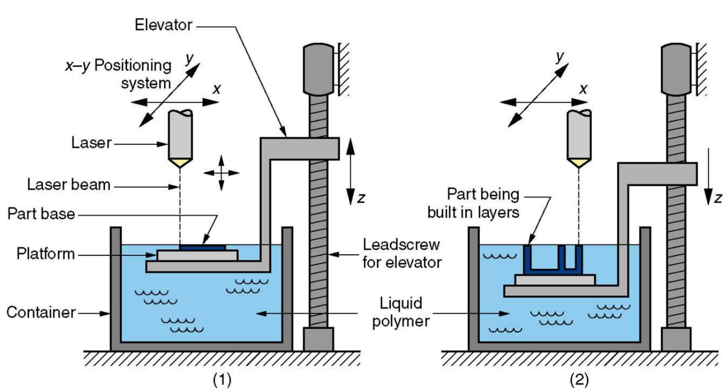
Introduction to Rapid Prototyping

1.1-Stereolithography (STL)

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 - each layer is added onto the previous layer to gradually build the 3-D geometry
- The first addition RP technology - introduced 1988 by 3D Systems Inc. based on the work of Charles Hull
- More installations than any other RP method

Stereolithography



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.

A part produced by stereolithography

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
- Starting materials are liquid monomers
- Polymerization occurs on exposure to UV light produced by laser scanning beam
  - Scanning speeds ~ 500 to 2500 mm/s

Part Build Time in STL

Time to complete a single layer :

$$T_i = \frac{A_i}{vD} + T_d$$

where T_i = time to complete layer i; A_i = area of layer i; v = average scanning speed of the laser beam at the surface; D = diameter of the "spot size," assumed circular; and T_d = delay time between layers to reposition the worktable

Part Build Time in STL - continued

Once the T_i values have been determined for all layers, then the build cycle time is:

$$T_c = \sum_{i=1}^{n_l} T_i$$

where T_c = STL build cycle time; and n_l = number of layers used to approximate the part

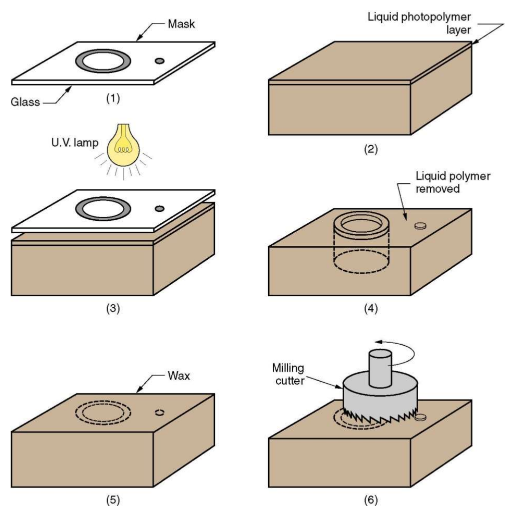
- Time to build a part ranges from one hour for small parts of simple geometry up to several dozen hours for complex parts

1.2- 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

Solid Ground Curing



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

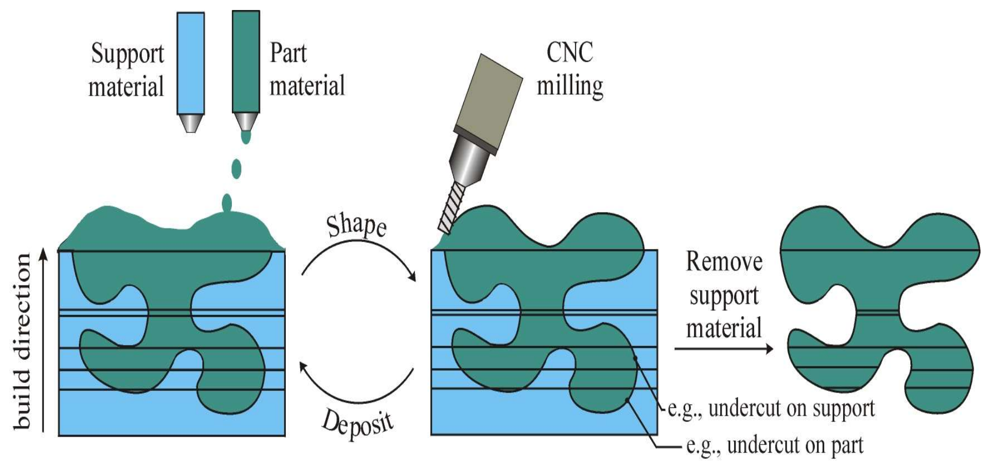
- Sequence for each layer takes about 90 seconds
- Time to produce a part by SGC is claimed to be about eight times faster than other RP systems
- The solid cubic form created in SGC consists of solid polymer and wax
- The wax provides support for fragile and overhanging features of the part during fabrication, but can be melted away later to leave the free-standing part

1.3- Droplet Deposition Manufacturing (DDM)

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

- Droplets cold weld to surface to form a new layer
- Deposition for each layer controlled by a moving x-y nozzle whose path is based on a cross section of a CAD geometric model that is sliced into layers
- Work materials include wax and thermoplastics

Droplet Deposition Manufacturing (DDM)



2- Solid-Based Rapid Prototyping Systems

- Starting material is a solid
- Solid-based RP systems include the following processes:

  2.1- Laminated object manufacturing

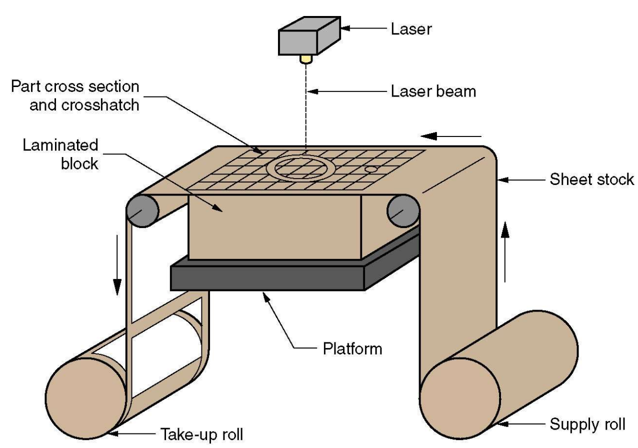
  2.2- Fused deposition modeling

2.1- Laminated Object Manufacturing (LOM)

Solid physical model 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 sheet stock includes paper, plastic, cellulose, metals, or fiber-reinforced materials
- The sheet 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

Laminated Object Manufacturing



Laminated object manufacturing.

2.2- Fused Deposition Modeling (FDM)

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

- 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
- 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

3- Powder-Based RP Systems

- Starting material is a powder
- Powder-based RP systems include the following:
  3.1- Selective laser sintering
  3.2- Three dimensional printing

3.1- Selective Laser Sintering (SLS)

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

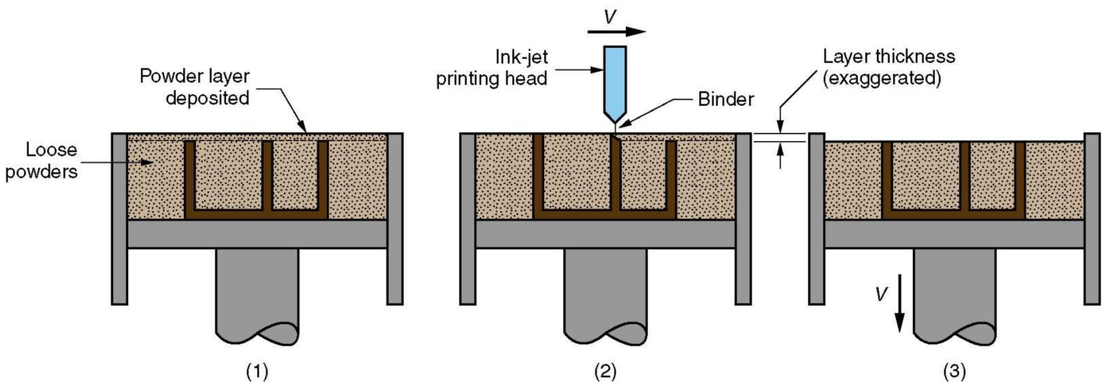
- After each layer is completed, a new layer of loose powders is spread across the surface
- Layer by layer, the powders are gradually bonded by the laser beam into a solid mass that forms the 3-D part geometry
- In areas not sintered, the powders are loose and can be poured out of completed part

3.2- Three Dimensional Printing (3DP)

Part is built layer-by-layer using an ink-jet printer to eject adhesive bonding material onto successive layers of powders

- Binder is deposited in areas corresponding to the cross sections of 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

Three Dimensional Printing



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

Design Applications

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

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 streamline shapes
  - Stress analysis of physical model
  - Fabrication of pre-production parts for process planning and tool design

Tooling Applications

- Called *rapid tool making* (RTM) when RP is used to fabricate production tooling
- Two approaches for tool-making:
  1. Indirect RTM method
  2. Direct RTM method

Indirect RTM Method

Pattern is created by RP and the pattern is used to fabricate the tool

- Examples:
  - Patterns for sand casting and investment casting
  - Electrodes for EDM

Direct RTM Method

RP is used to make the tool itself

- Example:
  - 3DP to create a die of metal powders followed by sintering and infiltration to complete the die

Manufacturing Applications

- Small batches of plastic parts that could not be economically molded by injection molding because of the high mold cost
- Parts with intricate 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

Thanks