UNIT-I
INTRODUCTION OF THE COURSE [ADDITIVE MANUFACTURING]

Course Objectives:

On completion of this course, the students should be able to:

- Impart fundamental knowledge on principles of rapid prototyping with the objective of increasing productivity and minimizing manufacturing time and cost.
- Identify and control important process parameters in the additive manufacturing for optimal performance of materials in manufacturing industries.

Scope of the course:

Additive manufacturing (AM) has the potential to completely redefine manufacturing in certain areas. So of course manufacturers of every size are now looking seriously at 3-D printing as a complement to existing and traditional manufacturing methods.

Implemented properly, additive manufacturing can significantly reduce material waste, reduce the amount of production steps, inventory being held, and reduce the amount of distinct parts needed for an assembly. Aerospace and medical industries lead additive manufacturing adoption.

Course Outcomes:

On successful completion of the course, the student will be able to:

- Describe additive manufacturing and identify the use of software for rapid prototyping.
- Choose materials from a range of materials for the given processes of additive manufacturing.
- Select the rapid prototyping process for the given prerequisites.
- Identify the different rapid tooling processes and emerging trends in rapid tooling.

UNIT-2
RAPID PRODUCT DEVELOPMENT

Introduction to Rapid Product Development:

One of the important steps prior to the production of a functional product is building of a physical prototype. Prototype is a working model created in order to test various aspects of a design, illustrate ideas or features and gather early user feed-back. Traditional prototyping is typically done in a machine shop where most of parts are machined on lathes and milling machines. This is a subtractive process, beginning with a solid piece of stock and the machinist carefully removes the material until the desired geometry is achieved. For complex part geometries, this is an exhaustive, time consuming, and expensive process. A host of new shaping techniques, usually put under the title Rapid Prototyping, are being developed as an alternative to subtractive processes. These methods are unique in that they add and bond materials in layers to form objects. These systems are also known by the names additive fabrication, three dimensional printing, solid freeform fabrication (SFF), layered manufacturing etc. These additive technologies offer significant advantages in many applications compared to classical subtractive fabrication methods like formation of an object with any geometric complexity or intricacy without the need for elaborate machine setup or final assembly in very short time. This has resulted in their wide use by engineers as a way to reduce time to market in manufacturing, to better understand and communicate product designs, and to make rapid tooling to manufacture those products. Surgeons, architects, artists and individuals from many other disciplines also routinely use this technology.

- Prototype: It is a model fabricated to prove out a concept or an idea.
- Solid Modelling: It's a branch of CAD that produces 2D or 3D objects in an electronic format.
- Definition: Rapid prototyping is basically an additive manufacturing process used to quickly fabricate a model of a part using 3-D CAM data.
- It can also be defined as layer by layer fabrication of 3D physical models directly from CAD.

Need for the compression in the product development

- To increase effective communication.
- To decrease development time.
- To decrease costly mistakes.
- To minimize sustaining engineering changes.
- To extend product life time by adding necessary features & eliminating redundant features early in the design.

Trends in manufacturing industries emphasis the following:

- Increasing the no of variants of products.
- Increase in product complexity.
- Decrease in product lifetime before obsolescence.
- Decrease in delivery time.
- Product development by Rapid prototyping by enabling better communication.

Conventional Machining:

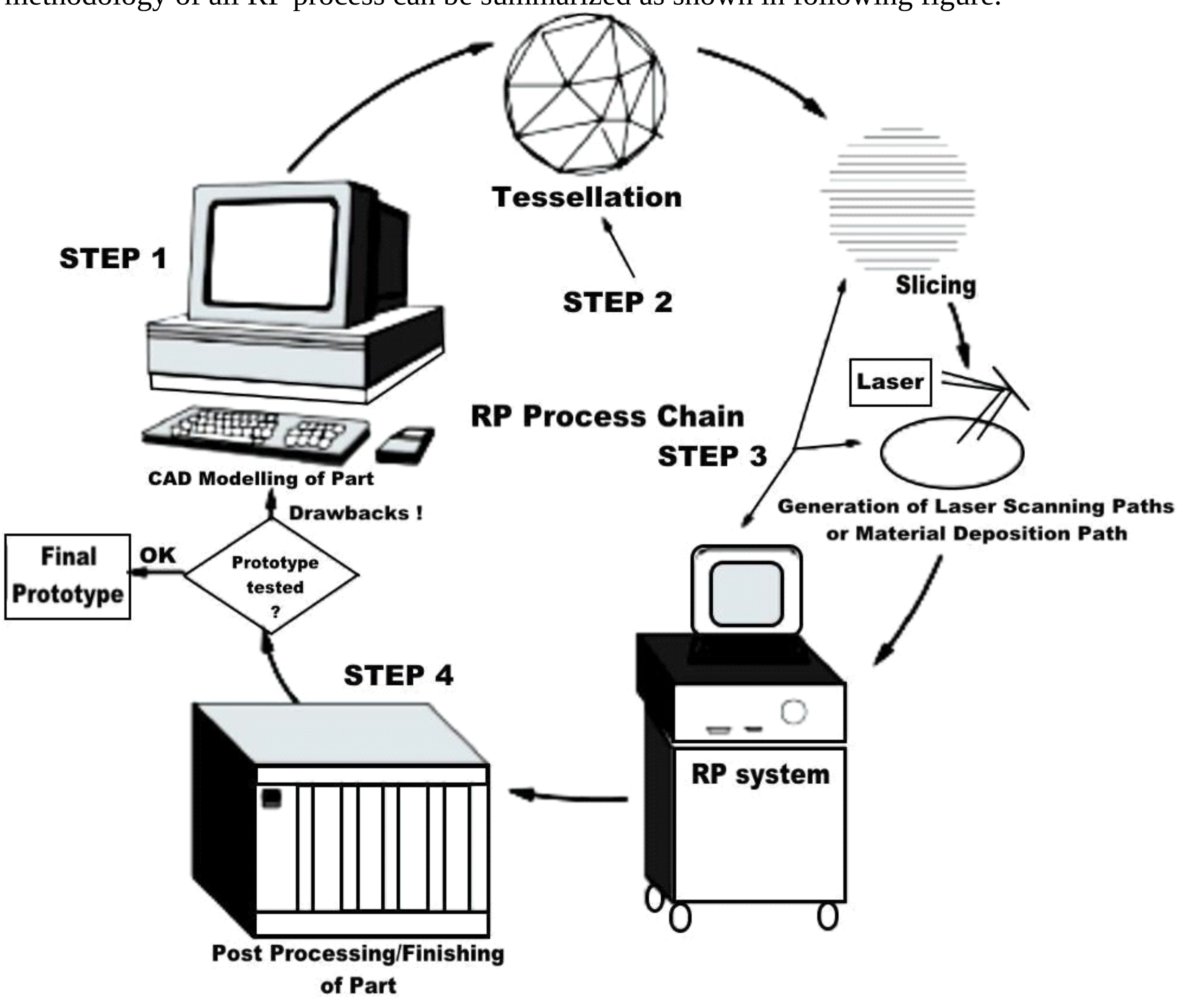
- Its not suitable for complex shapes because they are difficult to machine.

- Time consuming
- Very costly
- Tedious or very laborious.
- Skilled operator is required.
- Accuracy will be less.
- Increased product development time.

- Pre-processing:- CAD model slicing & setting algorithms applied for various RP systems.
- Post-processing:- Cleaning operations required to finish a part after removing it from RP machine.
- Materials for Rapid Prototyping:- Paper, Wax, Plastics, Resins, Metallic powders.

Methodology of Rapid Prototyping:

RP in its basic form can be described as the production of three dimensional (3D) parts from computer aided design (CAD) data in a decreased time scale. The basic methodology of all RP process can be summarized as shown in following figure.



Rapid prototyping process chain

- Construct a CAD model.
- Convert it to STL format.
- RP machine processes .STL file by creating sliced layers of model.
- First layer of model is created.
- Model is then lowered by thickness of next layer.
- Process is repeated until completion of model

- The model & any supports are removed.
- Surface of the model is then finished and cleaned.

- Development of a CAD model

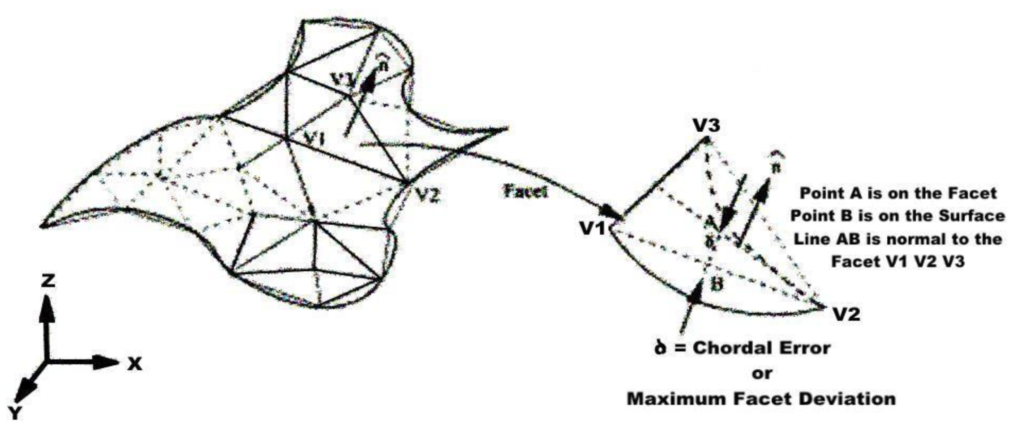
The process begins with the generation CAD model of the desired object which can be done by one of the following ways;

- Conversion of an existing two dimensional (2D) drawing
- Importing scanned point data into a CAD package
- Creating a new part in CAD in various solid modeling packages
- Altering an existing CAD model

RP has traditionally been associated with solid rather than surface modelling but the more recent trends for organic shapes in product design is increasing the need for free flowing surfaces generated better in surface modelling.

- Generation of Standard triangulation language (STL) file

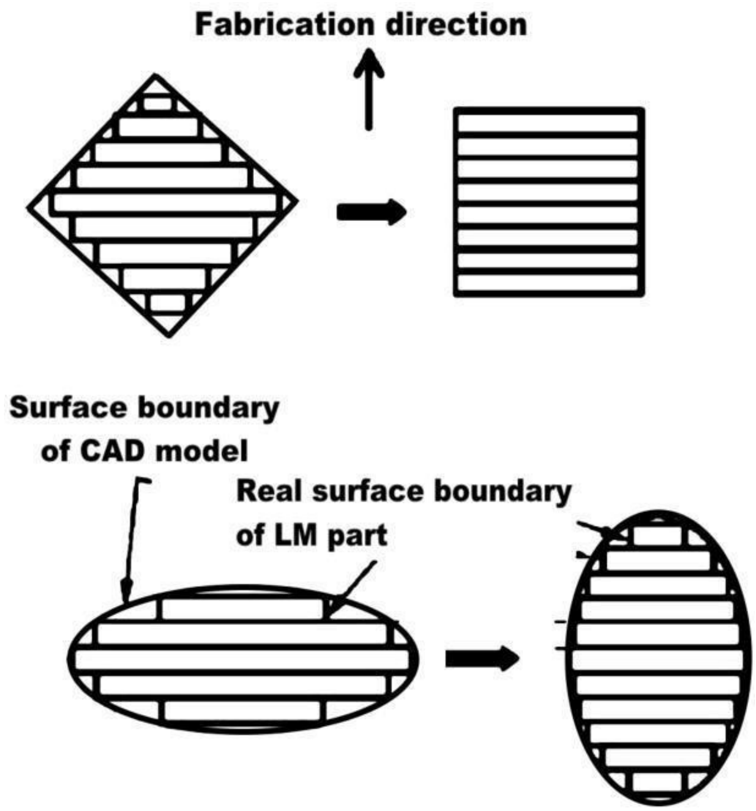
The developed 3D CAD model is tessellated and converted into STL files that are required for RP processes. Tessellation is piecewise approximation of surfaces of 3D CAD model using series of triangles. Size of triangles depends on the chordal error or maximum fact deviation. For better approximation of surface and smaller chordal error, small size triangle are used which increase the STL file size. This tessellated CAD data generally carry defects like gaps, overlaps, degenerate facets etc which may necessitate the repair software. These defects are shown in figure below. The STL file connects the surface of the model in an array of triangles and consists of the X, Y and Z coordinates of the three vertices of each surface triangle, as well as an index that describes the orientation of the surface normal.



Tessellation defects

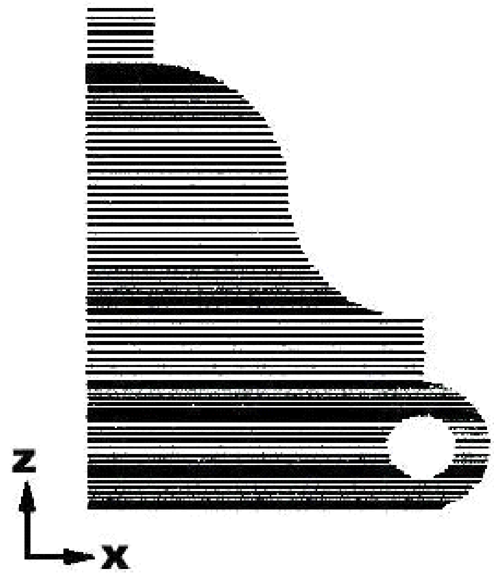
• Slicing the STL file

Slicing is defined as the creating contours of sections of the geometry at various heights in the multiples of layer thickness. Once the STL file has been generated from the original CAD data the next step is to slice the object to create a slice file (SLI). This necessitates the decision regarding part deposition orientation and then the tessellated model is sliced. Part orientation will be showing considerable effect on the surface as shown in the figures.



Effect of Part deposition Orientation

The thickness of slices is governed by layer thickness that the machine will be building in, the thicker the layer the larger the steps on the surface of the model when it has been built. After the STL file has been sliced to create the SLI files they are merged into a final build file. This information is saved in standard formats like SLC or CLI (Common Layer Interface) etc.



- Support Structures

As the parts are going to be built in layers, and there may be areas that could float away or of overhang which could distort. Therefore, some processes require a base and support structures to be added to the file which are built as part of the model and later removed.

- Manufacturing

As discussed previously, the RP process is additive i.e. it builds the parts up in layers of material from the bottom. Each layer is automatically bonded to the layer below and the process is repeated until the part is built. This process of bonding is undertaken in different ways for the various materials that are being used2 but includes the use of Ultraviolet (UV) lasers, Carbon Dioxide (C) lasers, heat sensitive glues and melting the material itself etc.

- Post processing

The parts are removed from the machine and post processing operations are performed sometimes to add extra strength to the part by filling process voids or finish the curing of a part or to hand finish the parts to the desired level. The level of post processing will depend greatly on the final requirements of the parts produced, for example, metal tooling for injection molding will require extensive finishing to eject the parts but a prototype part manufactured to see if it will physically fit in a space will require little or no post processing.

History of RP system

- It started in 1980’s
- First technique is Stereo lithography (SLA)
- It was developed by 3D systems of Valencia in California, USA in 1986.
- Fused deposition modeling (FDM) developed by stratasys company in 1988.
- Laminated object manufacturing (LOM) developed by Helisis (USA).
- Solid ground Curing developed by Cubitol corporation of Israel.
- Selective laser sintering developed by DTM of Austin, Texas (USA) in 1989.
- Sanders Model maker developed by Wilton incorporation USA in 1990.

- Multi Jet Modeling by 3D systems.
- 3-D Printing by Solygen incorporation, MIT, USA.

Applications

Most of the RP parts are finished or touched up before they are used for their intended applications. Applications can be grouped into

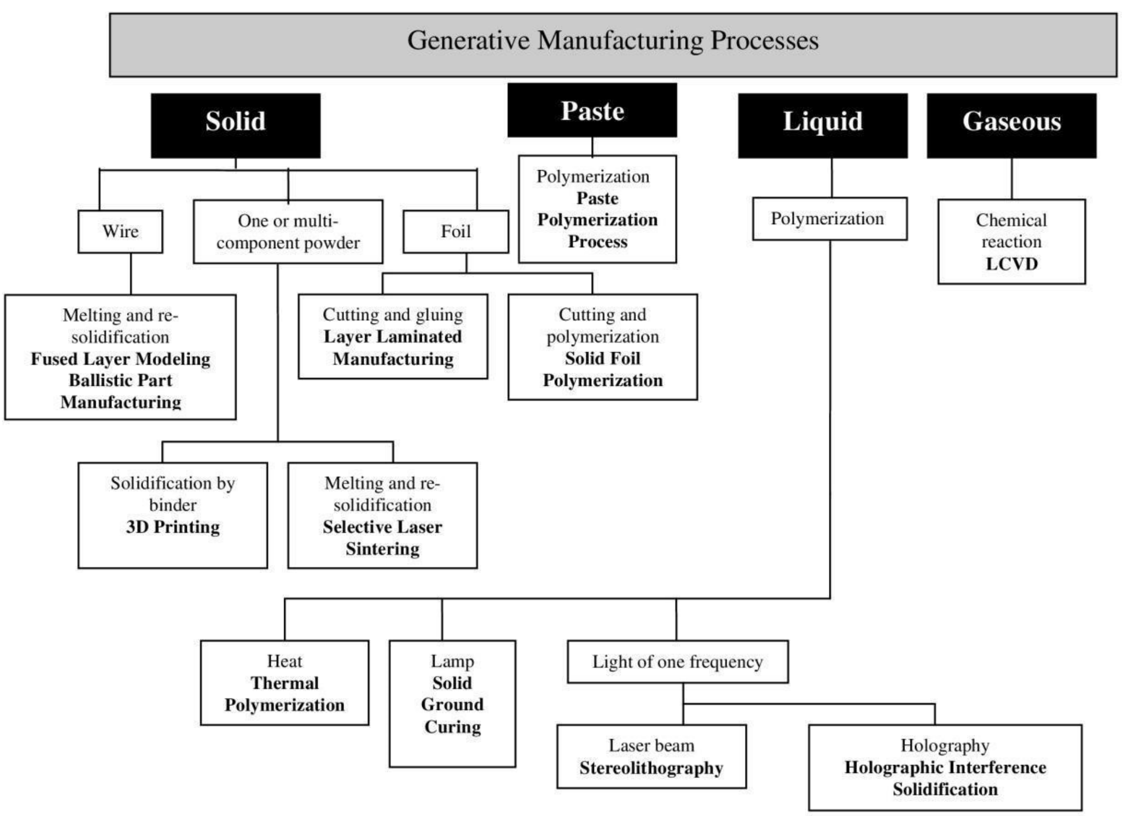
- Design (2) Engineering, Analysis, and Planning and (3) Tooling and Manufacturing. A wide rangeof industries can benefit from RP andthese include, but are not limited to, aerospace, automotive, biomedical, consumer, electrical and electronics products.

Classification of RP systems

The professional literature in RP contains different ways of classifying RP processes. However, one representation based on German standard of production processes classifies RP processes according to state of aggregation of their original material and is given in figure.

Here, few important RP processes namely
Stereo lithography (SLA)
Laminated Object Manufacturing (LOM)
Selective Laser Sintering (SLS)
Fused Deposition Modeling (FDM)

Solid Ground Curing (SGC) are described

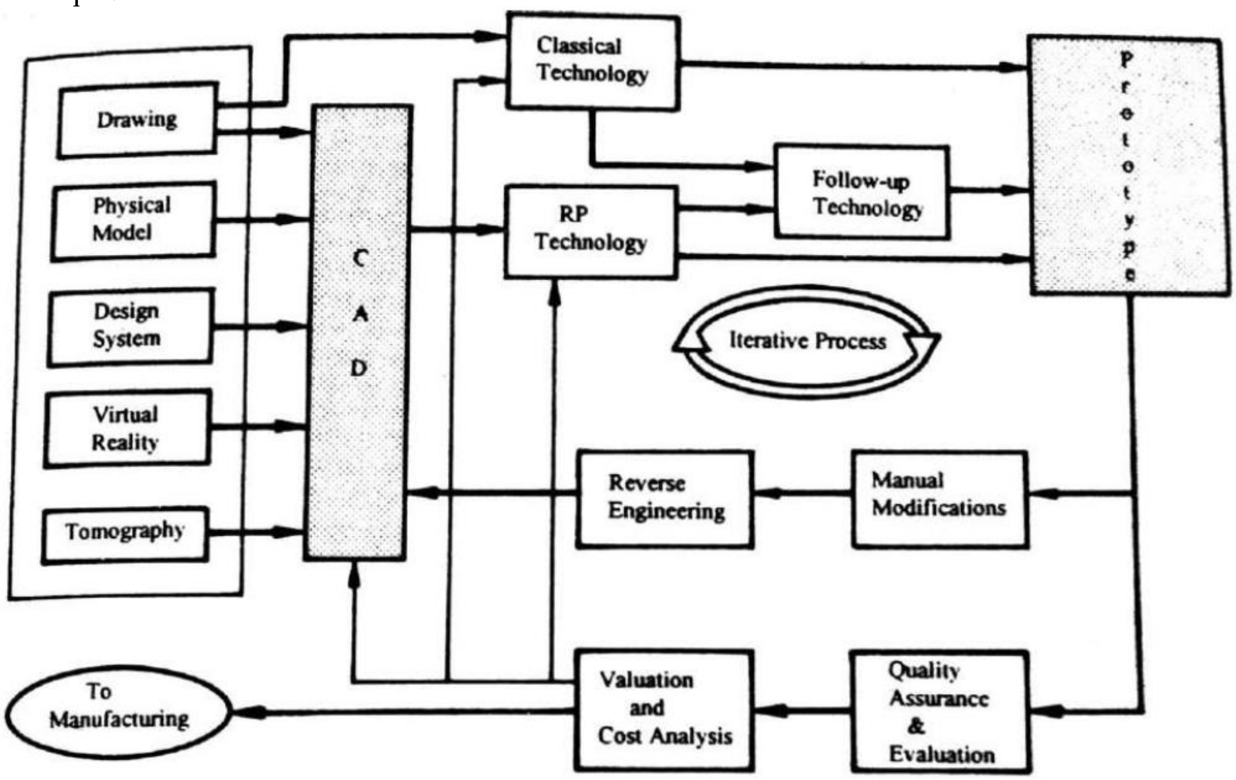


Classification of RP Processes

Definition of Rapid Product Development

Rapid product development (RPD) refers to recently developed technologies and techniques that assist manufacturers and designers in meeting the demands of shortened product development time. For example, injection-molding companies need to shorten tool and die development time drastically. By using reverse engineering, a three dimensional physical product or clay mock-up can be quickly captured in the digital form, remodeled, and exported for rapid prototyping/tooling or rapid manufacturing using multi-axis CNC machining techniques.

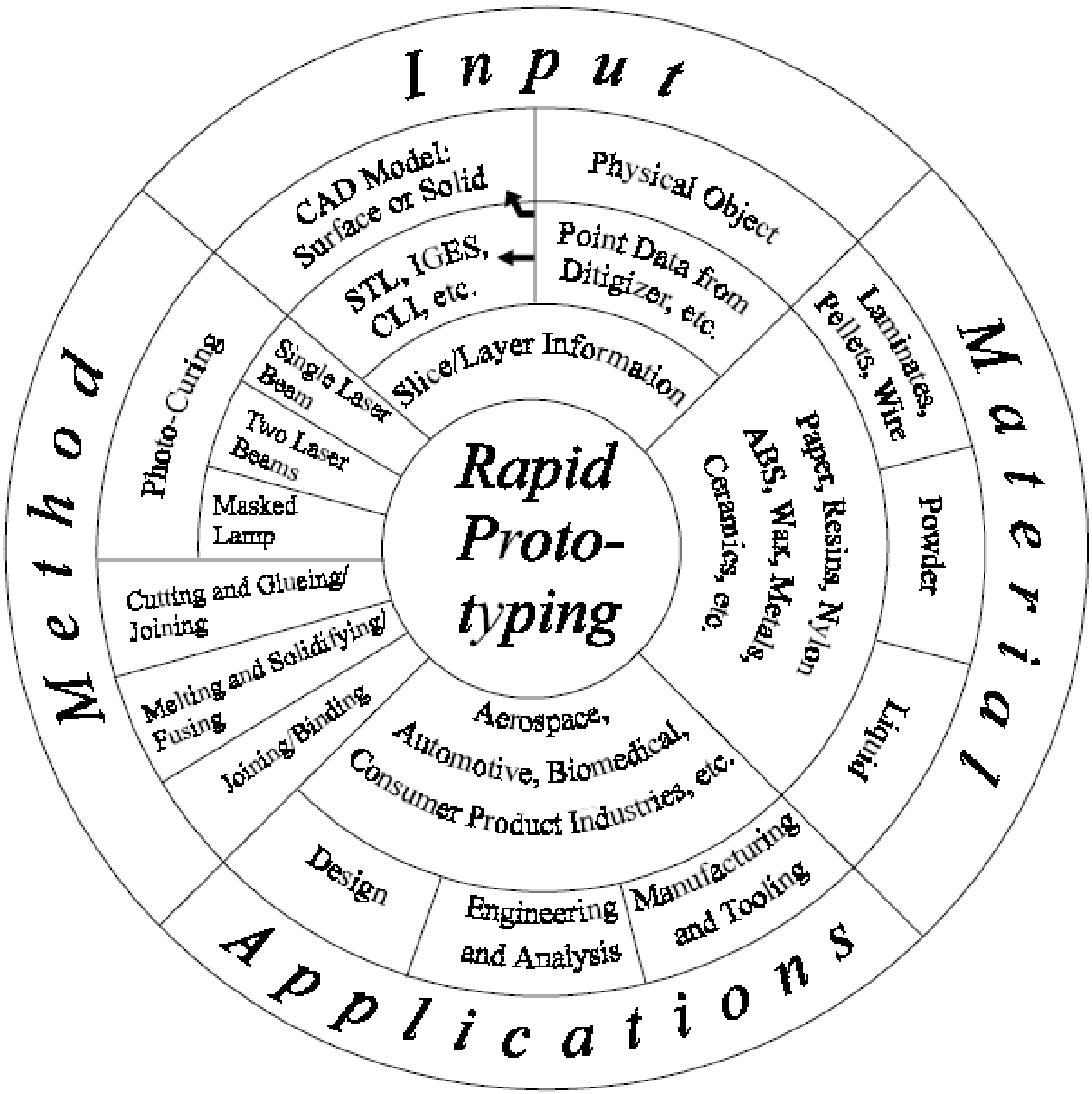
The figure below shows the whole process chain of rapid product development using RP technique.



Rapid Prototyping (RP)

Rapid prototyping is a group of techniques used to quickly fabricate a scale model of a physical part or assembly using three-dimensional computer aided design data. Rapid prototyping was termed because of the process this technology was designed to enhance or replace. Manufacturers and product developers used to find prototyping a complex, tedious, and expensive process that often impeded the developmental and creative phases during the introduction of a new product. RP was found to significantly speed up this process and thus the term was adopted. However, users and developers of this technology now realize that AM technology can be used for much more than just prototyping.

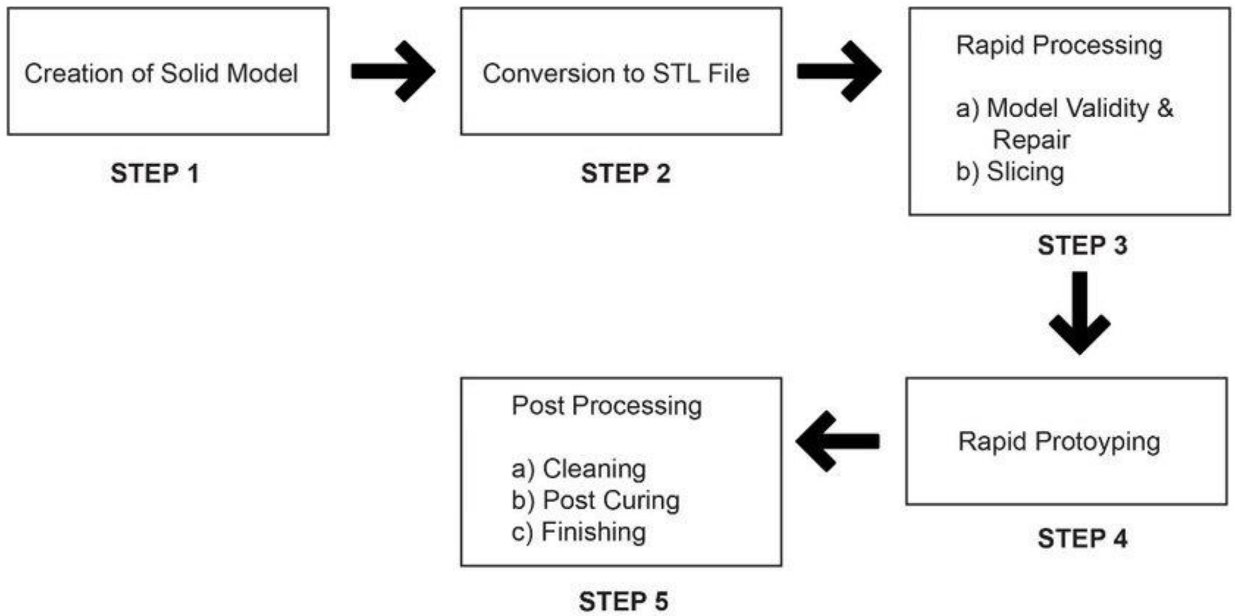
Fundamentally, the development of RP can be seen in four primary areas. The Rapid Prototyping Wheel in Figure 1.3 depicts these four key aspects of Rapid Prototyping. They are: Input, Method, Material and Applications.



Principle of RP

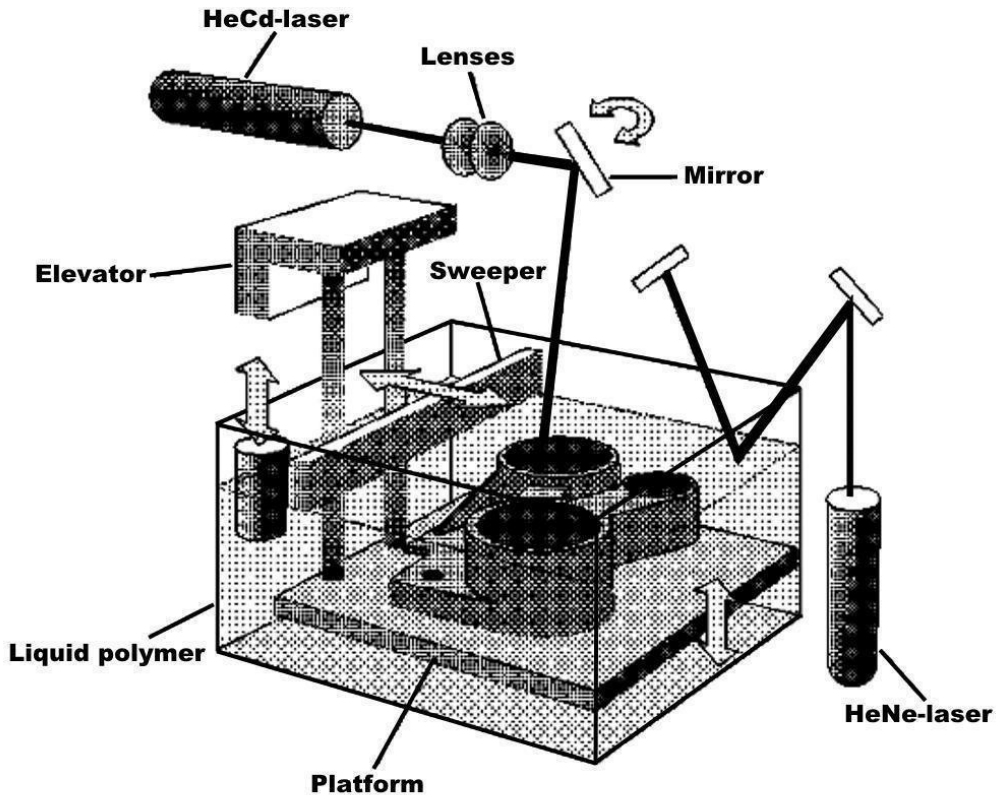
Basic principle of working of RP involves 5 steps:

1. Creation of the CAD model of the design
2. Conversion of the CAD model to STL format
3. Slicing the STL file into 2-D cross-sectional layers
4. Layer by layer construction
5. Cleaning and finishing the model


Creation of Solid Model
STEP 1
Conversion to STL File
STEP 2
Rapid Processing
a) Model Validity & Repair
b) Slicing
STEP 3
Rapid Protoyping
STEP 4
Post Processing
a) Cleaning
b) Post Curing
c) Finishing
STEP 5

UNIT-3
STEREOLITHOGRAPHY

Introduction:
It is the first RP system developed by 3D SYSTEMS of Valencia in California, USA in 1996.
First Model developed was 250/50 followed by 250/30, 3500, 5000 and 7000.



Principle:
SLA is a laser based Rapid Prototyping process which builds parts directly from CAD by curing or hardening a photosensitive resin with a relatively low power laser.

Stereo Lithography (SL) is the best known rapid prototyping system. The technique builds three-dimensional models from liquid photosensitive polymers that solidify when exposed to laser beam. The model is built upon a platform in a vat of photo sensitive liquid. A focused UV laser traces out the first layer, solidifying the model cross section while leaving excess areas liquid. In the next step, an elevator lowers the platform into the liquid polymer by an amount equal to layer thickness. A sweeper recoats the solidified layer with liquid, and the laser traces the second layer on the first. This process is repeated until the prototype is complete. Afterwards, the solid part is removed from the vat and rinsed clean of excess liquid. Supports are broken off and the model is then placed in an ultraviolet oven for complete curing.

Parameters:
Laser Type: Helium Cadmium Laser (He-Cd)
Laser Power: 24mW
Laser Life: 2000
hours Re-coat
material: Zaphir
Minimum Slice Thickness:
0.1mm Beam Diameter:
0.2mm
Scan Speed: 0.75m/sec
Maximum Part Volume: 0.25x0.25x0.25 m
Maximum Part Weight: 9 kgs

Application Range

- Processing large variety of photo-sensitive polymers including clear, water resistant and flexible resins
- Functional parts for tests
- Tools for pre series production tests.
- Manufacturing of medical models
- Manufacturing of electro-forms for Electro Discharge Machining (EDM)
- Form-fit functions for assembly tests.

Advantages

- Possibility of manufacturing parts which are impossible to produce conventionally using a single process.
- Continuous unattended operation for 24 hours.
- High resolution.
- Any geometrical shape can be made with virtually no limitation.

Disadvantages

- Necessity to have support structures
- Accuracy not in the range of mechanical part manufacturing.
- Restricted areas of application due to given material properties.
- Labour requirements for post processing, especially cleaning.

Software:

- SLA CONTROL AND SET UP SOFTWARE: It operates on SLA 250 and SLA 500 machines. It has got three packages.
  - SLA VIEW: UNIX based system for viewing and positioning.
  - BRIDGE WORKS: UNIX based software for generating support structures.
  - SLA SLICE: Slicing and system operation software.
- MAESTRO: UNIX based software
- MS WINDOWS NT SOFTWARE (3D LIGHT YEAR): It is used for viewing,

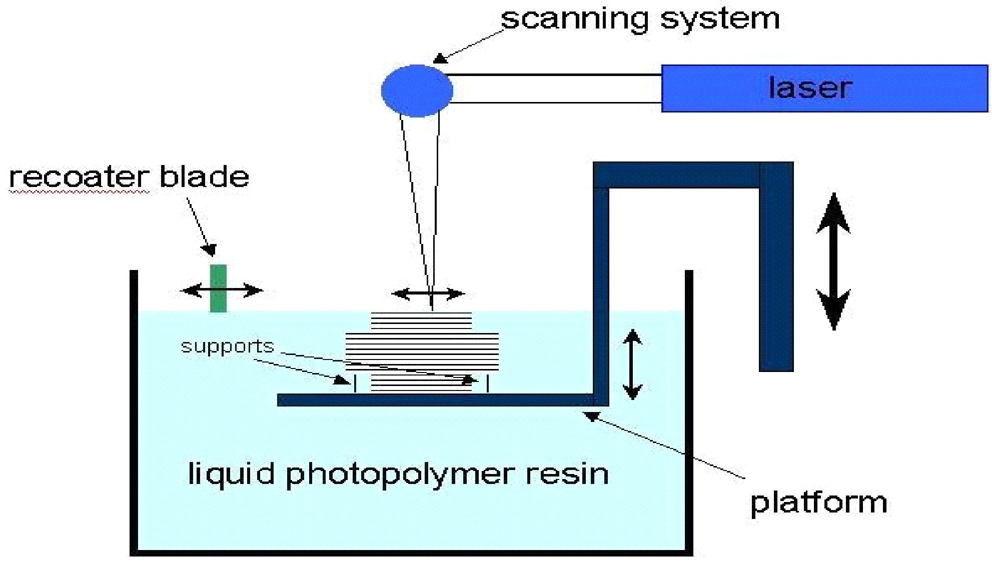
positioning, support generation and slicing, build station for operating SLA machine.

Build Materials Used:
Epoxy Resin, Acrylate Resin

Epoxy Resin has better material properties and less hazardous but require large exposure time for curing.

SLA HARDWARE:
The build chamber of SLA contains

- A removable VAT that holds the build resin.
- A detachable perforated build platen on a Z axis elevator frame
- An automated resin level checking apparatus
- VAT has a small amount of Z movement capability which allows computer to maintain a exact height per layer.
- A recoated blade rides along the track at the top of the rack and serves to smooth the liquid across the part surface to prevent any rounding off edges due to cohesion effects.
- Some systems have Zaphyrrecoater blade which actually softens up resin and delivers it evenly across the part surface.
- Behind the build chamber resides the laser and optics required to cure resin.
- Laser unit is long rectangular about 4 feet long and remains stationary.



Stereolithography Apparatus Operation:

- The process begins with the solid model in various CAD formats
- The solid model must consist of enclosed volumes before it is translated form CAD format into .STL FILE

- The solid model is oriented into the positive octant of Cartesian co- ordinate system and then translate out Z axis by at least 0.25 inches to allow for building of supports
- The solid model is also oriented for optimum build which involves placing complex curvatures in XY plane where possible and rotating for least Z height as well as to where least amount of supports are required
- The .STL FILE is verified
- The final .STL FILE one which supports in addition to original file are then sliced into horizontal cross sections and saved as slice file.
- The slice files are then masked to create four separate files that control SLA machine ending with 5 extensions L, R, V and PRM.
- Important one is V file. I.e. Vector file. The V file contains actual line data that the laser will follow to cure the shape of the part.
- R file is the range file which contains data for solid or open fields as well as re-coater blade parameters.

The four build files are downloaded to SLA which begins building supports with platen adjust above the surface level. The first few support layers are actually cured into perforations into platen, thus providing a solid anchor for the rest of the part.

By building, SLA uses laser to scan the cross section and fill across the surface of resin which is cured or hardened into the cross sectional shape. The platen is lowered as the slices are completed so that more resin is available in the upper surface of the part to be cured. Final step is Post Processing.

Post Processing:

- Ultraviolet Oven (Post Curing Apparatus) 2) An Alcohol Bath.

Clean the part in the alcohol bath and then go for final curing.

Advantages:

- Parts have best surface quality
- High Accuracy
- High speed
- Finely detailed features like thin vertical walls, sharp corners & tall columns can be fabricated with ease.

Disadvantages:

- It requires Post Processing. i.e. Post Curing.
- Careful handling of raw materials required.
- High cost of Photo Curable Resin.

Applications:

- Investment Casting.
- Wind Tunnel Modelling.
- Tooling.
- Injection Mould Tools.

Diagram:

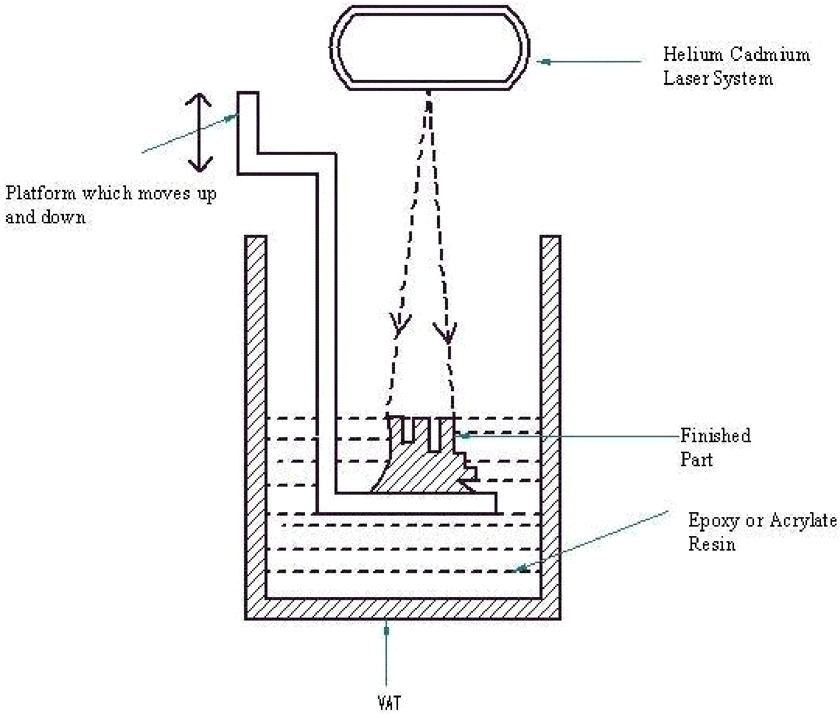


Fig: Stereolithography Apparatus

UNIT-4
SELECTIVE LASER SINTERING & FUSION DEPOSITION MOULDING

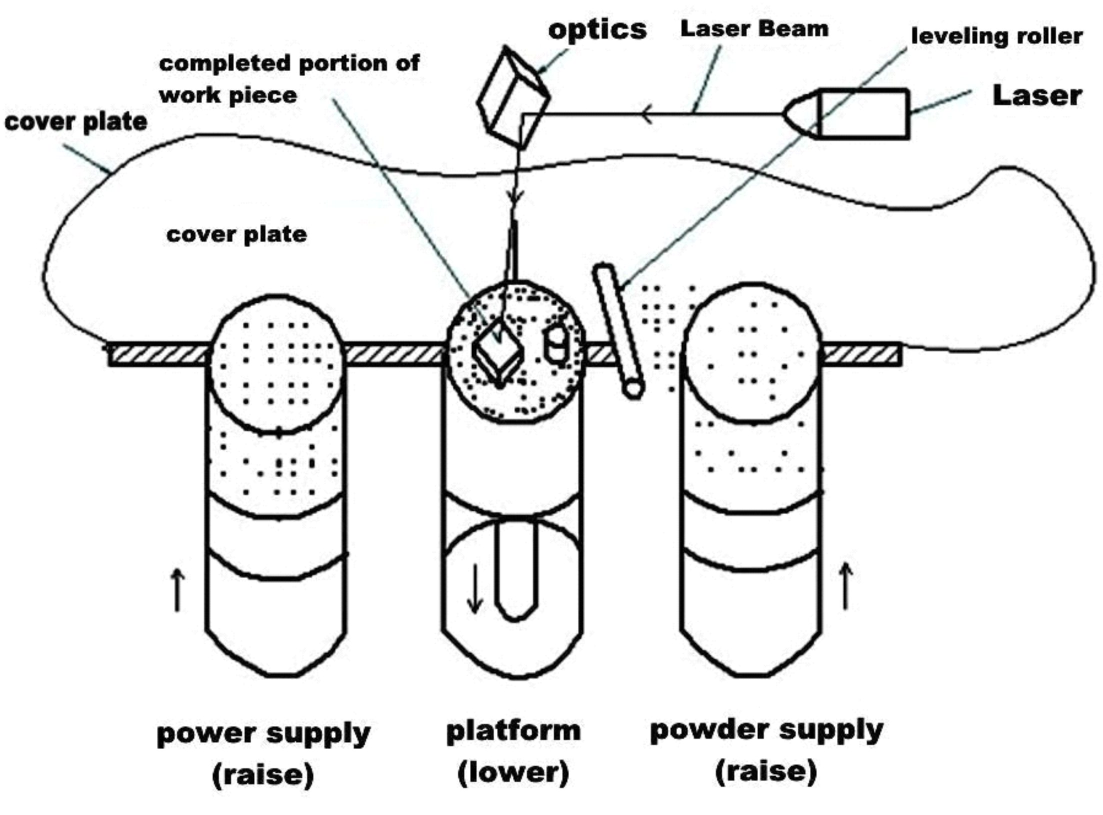
SELECTIVE LASER SINTERING:

Selective Laser Sintering is a rapid prototyping process that builds models from a wide variety of materials using an additive fabrication method. Selective Laser Sintering was developed by university of Texas Austin in 1987.The build media for Selective Laser Sintering comes in powder form which is fused together by a powerful carbon dioxide laser to form the final product.

DTM sinter station 2500 is the machine used for the process.

Selective Laser Sintering begins like most other rapid prototyping processes with a standard .STL CAD file format.DTM view software uses the .STL files. This software do the required orientation and scaling of parts.

This machine has auto nesting capabilities which will place multiple part optimally in the build chamber for best processing speed and results. Once the .STL file is placed and parameters are set the model is directly built from the file.



selective laser sintering

The sinter station has built piston at the center and feed piston on the either side. The model is built layer by layer like other rapid prototyping process so that the build piston will begin at the top of its range and will lower in increments of the set layer size as parts are built. With the build piston at the top a thin layer of powder is spread across the build area by the roller from one of the feed piston. The laser then cures in a raster sweeps motion across the area of the parts being built.The part piston lowers and more powder is deposited and the process is continued until all of the part is built.The build media is removed from the machine. It is a cake of powder. This cake is taken to the breakout station where excess powder is removed from the part manually with brushesthe excess powder that has been removed can be kept for recycling and can be reused. Some material needs additional finishing.

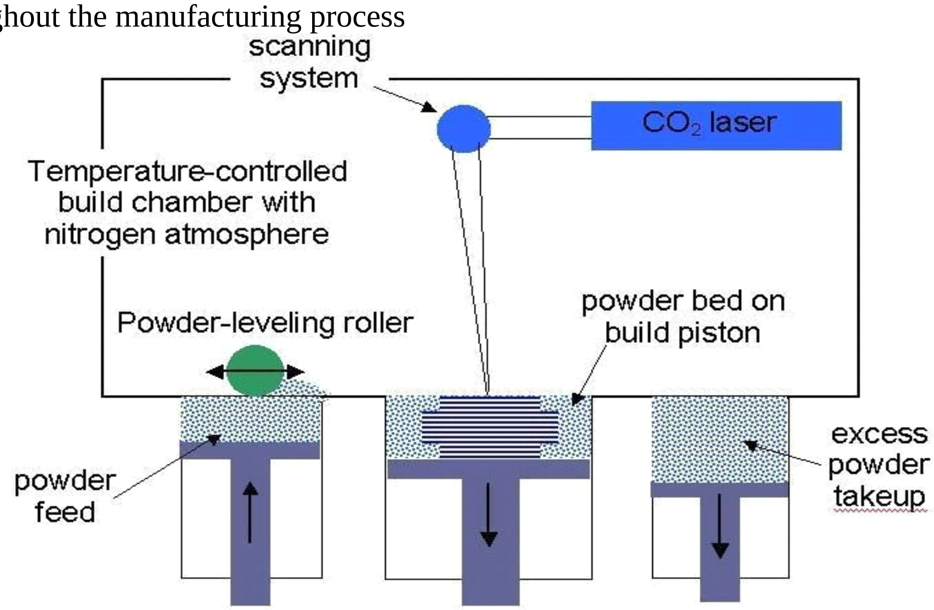
finishing techniques include grid blasting, sanding, polishing, drilling, taping and coatin

Purpose of Selective Laser Sintering:

To provide a prototyping tool

To decrease the time and cost of design to product cycle.

It can use wide variety of materials to accommodate multiple application throughout the manufacturing process



Applications:

1. As conceptual models.
2.Functional prototypes.
3.As Pattern masters.

Advantages:

- Wide range of build materials.
- High throughput

capabilities.

- 3.Self-supporting build envelop. 4.Parts are completed faster.
- Damage is less.
- Less wastage of material

Disadvantages:

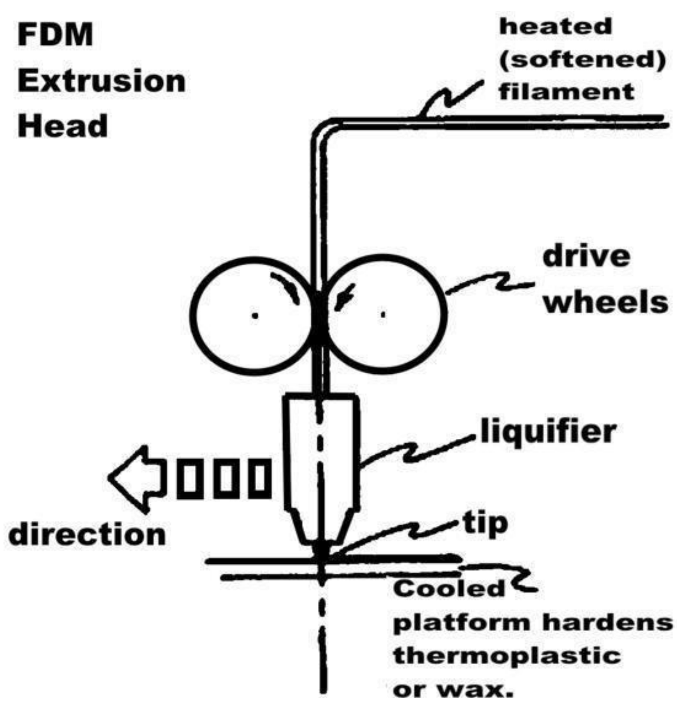
- Initial cost of system is high.
- High operational and maintenance cost.

3.Peripheral and facility requirement.

FUSION DEPOSITION MOULDING:

Fused Deposition Modelling is an extrusion based rapid prototyping process although it works on the same layer by layer principle as other RP systems. Fused Deposition Modelling relies on standard STL data file for input and is capable of using multiple build materials in a build or support relationship.

Fused Deposition Modeling (FDM) machine is basically a CNC- controlled robot carrying a miniature extruder head. By feeding the head with a plastic wire, solid objects are built "string by string". In this technique, filaments of heated thermoplastic are extruded from a tip that moves in the x-y plane. Like a baker decorating a cake, the controlled extrusion head deposits very thin beads of material onto the build platform to form the first layer. The platform is maintained at a lower temperature, so that the thermoplastic quickly hardens. After the platform lowers, the extrusion head deposits a second layer upon the first. Supports are built along the way, fastened to the part either with a second, weaker material or with a perforated junction.



Software Used:

FDM machine uses Quick Slice software to manipulate and prepare the incoming STL date for use in FDM machines. Software can be operated on various types of workstations from UNIX to PC based.

Build Materials:

- Investment Casting Wax.
- Acrilonitrile Butadiene Styrene plastic.
- Elastomer.

Extrusion Head:

- It is a key to FDM technology.
- Compact and removable unit.
- It consists of Dry Blocks, Heating Chamber and Tips.

Dry Blocks:

- These are raw material feeding mechanisms and are mounted on back of head.
- These are computer controlled.
- Capable of precision loading and unloading of filament.
- It consists of two parallel wheels attached to a small electric motor by gears.
- The wheels have a plastic and rubber thread and are spaced approximately 0.07inches apart and turn opposite to one another.
- When the wheels are turned in and end of the filament is placed between them, they continue to push or pull the material depending on direction of rotation.
- When loading the filament is pushed horizontally into the head through a hole, a little longer than the filament diameter which is the entry to the heating chamber.

Heating Chamber:

- It is a 90' curved elbow wrapped in a heating element which serves two primary functions
  - To change the direction of the filament flow so that the material is extruded vertically downwards.
  - To serve as a melting area for the material
- The heating element is electronically controlled and has feedback thermocouple to allow for a stable temperature throughout.
- The heating elements are held at a temperature just above the melting point of the material so that the filament passes from the exit of the chamber is in molten state. This allows for smooth extrusion as well as time control on material placement.
- At the end of the heating chamber which is about 4 inch long is the extrusion orifice or tip.

Tip:

- The two tips are externally threaded and screwed up into the heating chamber exit and are used to reduce the extruded filament diameter to allow for better detailed modelling
- .The tips are heated by heating chamber up to above the melting point of the material.

- The tips can be removed and replaced with different size openings, the two most common being 0.012 inch and 0.025 inches.
- The extruding surface of the tip is flat serving as the hot shearing surface to maintain a smooth upper finish of extruded material.
- The tip is the point at which the material is deposited onto a foam substrate to build the model..

Build Substrate:

- The foam substrate is an expendable work table once which parts are built.
- The substrate is about 1 inch thick and is passed on into a removable tray by one quarter inch pins.
- The foam used is capable of withstanding higher temperature. As for the first few layers of the part, the hot extrusion orifices are touching the substrate.
- The support material is used to support overhangs, internal cavities and thin sections during extrusion as well as to provide a base to anchor (part) to the substrate while building.

FDM OPERATION:

- CAD file preparation:
  - Before building the part, the STL file has to be converted into the machine language understood by FDM. Quick Slice software is used for this purpose.
  - The STL file is read into Quick Slice and is displayed graphically on screen in Cartesian co-ordinate system (XYZ)
  - Building box represents maximum build envelope of FDM.
  - Quick slice gives us options on the FDM system being used, the slice layer thickness, the build and support materials as well as tip sizes.
- Part Size:

The part must fit into the building box, if not it will either have to be scaled down to fit or be sectioned so that the pieces can be built separately and then bonded together later.

- Orientation and Positioning:

Once the part has been built in appropriate built size, the part should be oriented in an optimum position for building. The shape of the part plays an important role in this, in that some orientations may require less supporting of overhangs than the others.

- Slicing:

Once the part has been properly oriented and or scaled it must be sliced. Slicing is a software operation that creates thin horizontal cross sections of STL file that will later be used to create control code for the machine.

In Quick Slice, the slice thickness can be changed before slicing, the typical slices ranging from 0.005 inches to 0.015 inches.

Quick Slice allows

- To perform simple editing functions on slice files. Also editing function allows repair of minor flaws in the STL file with the options of closing and merging of curves.

Build Parameters:

- Sets:

Quick Slice uses sets or packages of build parameters. Sets contain all of the build instructions for a selected set of curves in a part. Sets allow a part to be built with several different settings
E.g. One set may be used for supporting structure of the part, one for part face, another for thicker sections of the part and still another for exposed surfaces of the part. This allows flexibility of building bulkier sections and internal fills quickly by getting finer details on visible areas of a part.
Sets also allow chosen sections of a part to build hollow, cross hatched or solid if so desired.
Two of the build parameters commonly worked with are road width and fill spacing.

- Road Width:

Road Width is the width of the ribbon of molten material that is extruded from the tip.

When FDM builds a layer, it usually begins by outlining the cross section with a perimeter road, sometimes followed by one or more concentric contours inside of perimeters.
Next it begins to fill remaining internal area in a raster or hatched pattern until a complete solid layer is finished.

Therefore three types of roads are Perimeter,
Contour and Raster.

- Fill Spacing:

Fill spacing is the distance left between raster's or contours that make up interior solids of the parts. A fill spacing set at zero means that part will be built solid.

- Creating and Outputting Roads:

Once all parameters have been set, road are created graphically by Quick Slice. The user is then allowed to preview each slice if so desired to see if the part is going to build as required.

- Getting a Build Time Estimate:

Quick slice has a very good build time estimator which activates when an SML file is written. SML stands for Stratasys Machine Language. Basically it displays in the command windows, the approximate amount of time and material to be used for given part. Build time estimate allows for a efficient tracking and scheduling of FDM system work loads.

- Building a part:

The FDM receives a SML file and will begin by moving the head to the extreme X and Y portions to find it and then raises the platen to a point to where the foam substrate is just below heated tips. After checking the raw material supply and temperature settings, the user then manually places the head at point where the part has to be built on the foam and then presses a button to begin building. After that FDM will build part completely without any user intervention.

- Finishing a FDM part:

FDM parts are an easiest part to finish.

Applications:

- Concept or Design Visualization.
- Direct Use Components.
- Investment Casting.
- Medical Applications
- Flexible Components.
- Conceptual modeling.
- Fit, form and functional applications and models for further manufacturing procedures.
- Investment casting and injection molding.

Advantages:

- Strength and temperature capability of build materials.
- Safe laser free operation.
- Easy Post Processing.
- Quick and cheap generation of models.
- Easy and convenient date building.
- No worry of possible exposure to toxic chemicals, lasers, or a liquid polymer bath.
- No wastage of material during or after producing the model.
- No requirement of clean-up.
- Quick change of materials.

Disadvantages:

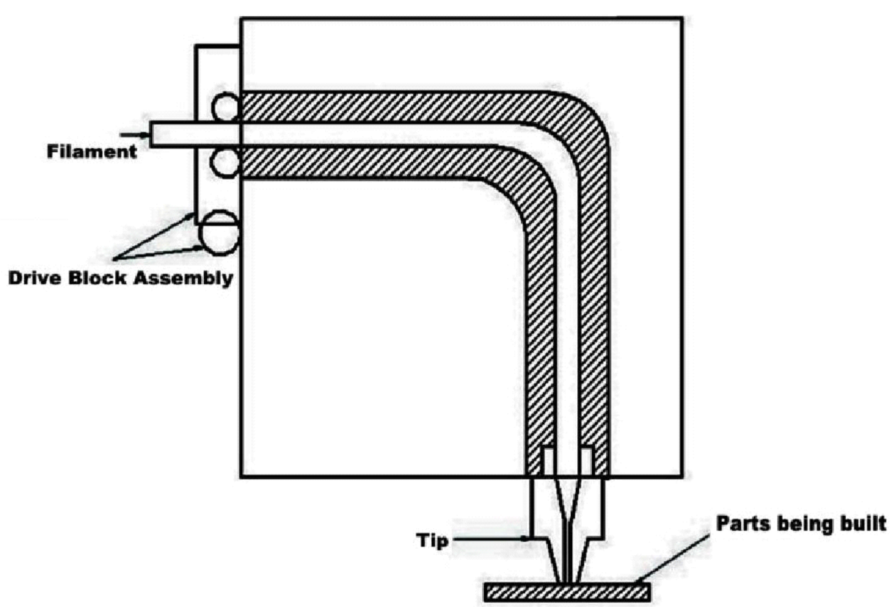
- Process is slower than laser based systems.
- Build Speed is low.
- Thin vertical column prove difficult to build with FDM.
- Physical contact with extrusion can sometimes topple or at least shift thin vertical columns and walls.

- Restricted accuracy due to the shape of the material used: wire of 1.27 mm diameter.

FDM Material Properties:

Material	Tensile Strength (Mpa)	Tensile Modulus (Mpa)	Flexural Strength (Mpa)	Flexural Modulus (Mpa)
ABDP400	35.2	1535	66.9	2626
Medical Grade ABSP 500	38	2014	58.9	1810
Investment casting wax (ICW06)	3.6	282	49.6	282
Elastomer	6.55	70	89.69	141

Diagrams:



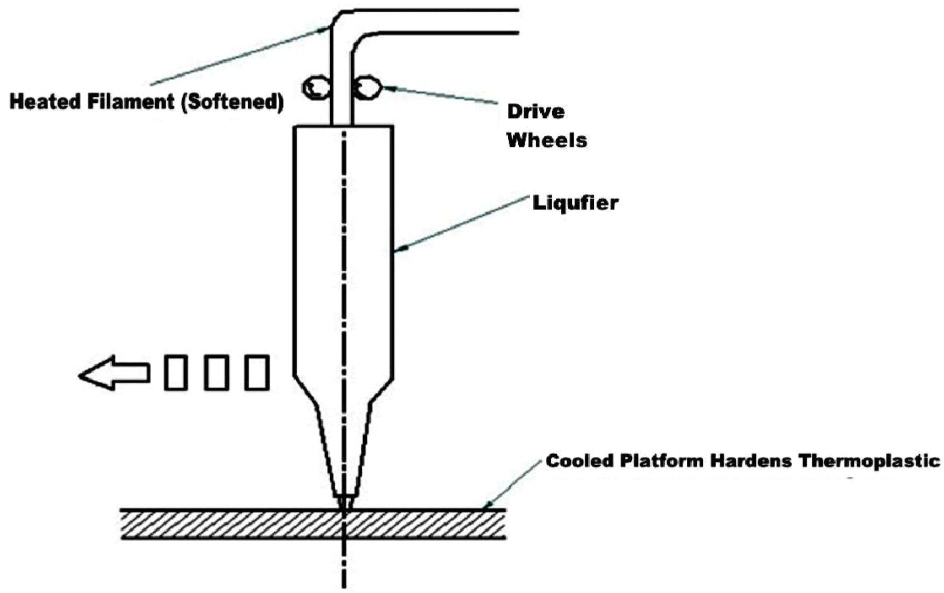


Fig a: FDM Extrusion Head

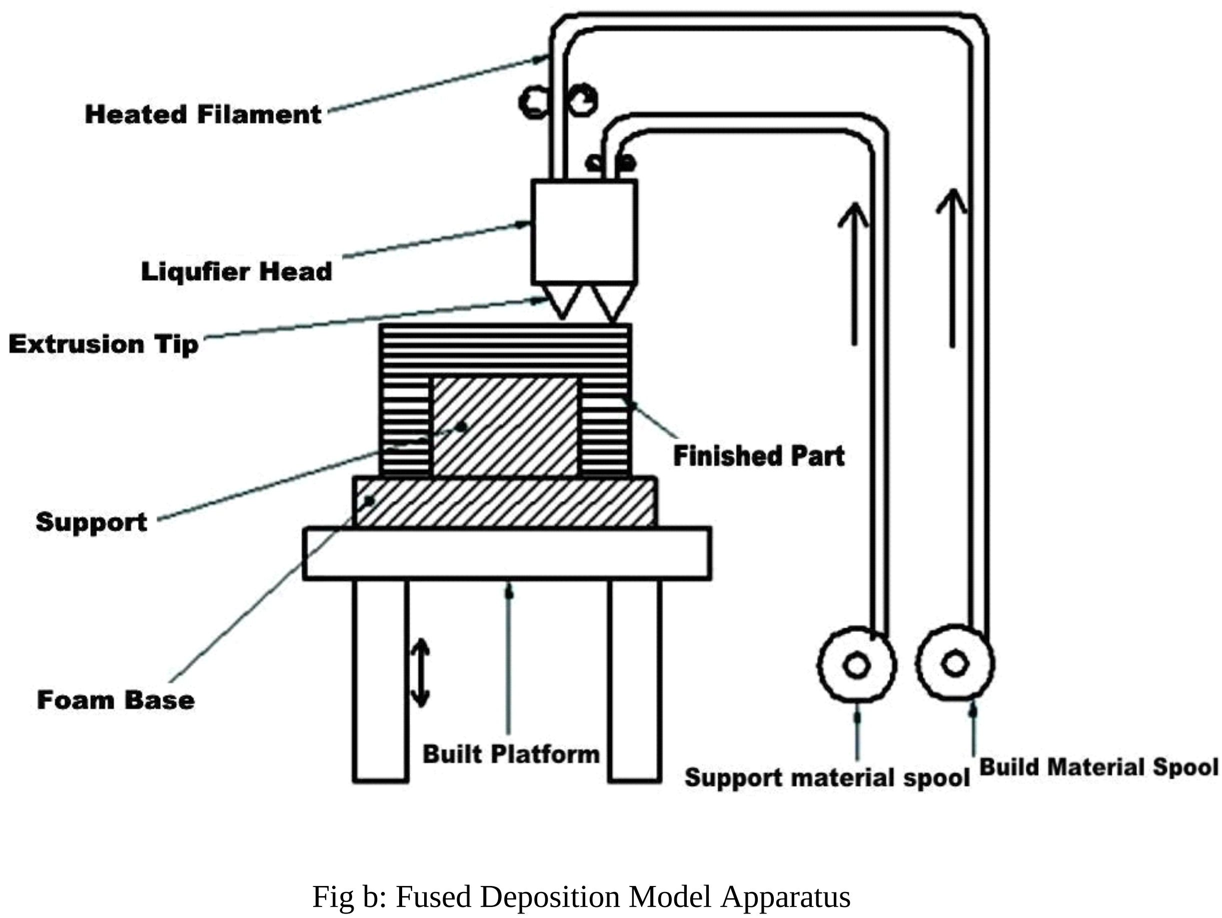
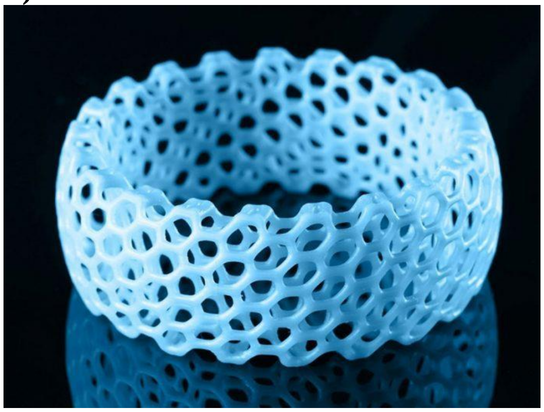


Fig b: Fused Deposition Model Apparatus

UNIT-5
SOLID GROUND CURING

Solid Ground Curing (SGC)

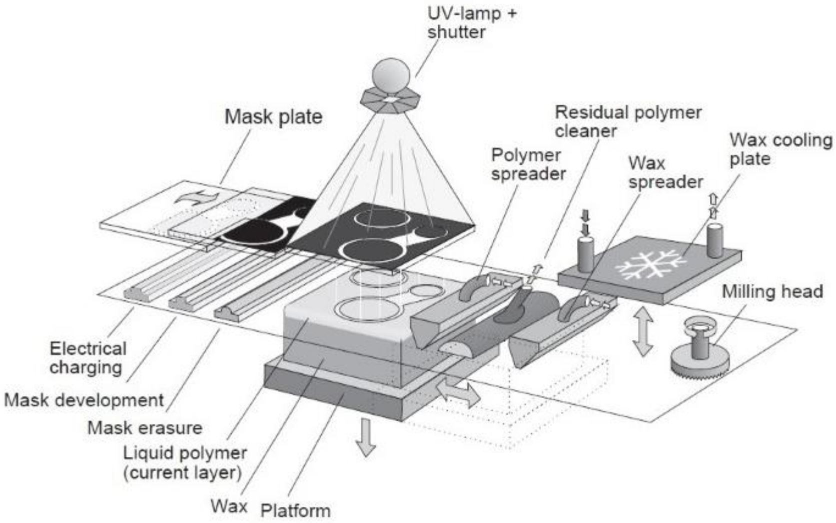


Solid ground curing (SGC) is a photograph polymer-based added substance assembling or 3D printing innovation utilized for delivering models, models, examples, and creation parts. In which the generation of the layer geometry is completed by methods for a powerful UV light through a veil. As the premise of strong ground curing is the presentation of each layer of the model by methods for a light through a cover, the preparing time for the age of a layer is free of the nature of the layer.

History of Solid Ground Curing

Solid Ground Curing (SGC) was produced and marketed by Cubital Ltd. of Israel in 1986 in the elective name of Solider Framework. While the strategy offered great exactness and a high creation rate, it experienced high securing and working expenses because of framework unpredictability. This prompted poor market acknowledgment.

While the organization still exists, frameworks are never again being sold. Overall, it is yet an intriguing case of the advances other than Stereolithography. Its pre-deceasing quick prototyping process that likewise uses photograph polymer materials. However, Objet Geometries Ltd. of Israel held protected innovation of the procedure after the conclusion of Cubital Ltd. in 2002 the innovation is never again being delivered.



Strong Ground Curing was initially created and sold by Cubital Ltd. of Israel. Their framework was exceptionally overwhelming and in this manner experienced high beginning and working costs that in the end caused their defeat. The organization never again exists and Objet Geometries, Ltd in Israel has procured its protected innovation.

Highlights of Solid Ground Curing

You can use high speed for production of large parts: 500*500 quickly. To create masks you need to follow a laser-like printing process and expose the full later all at once. Moreover no post-cure is required which fosters for a quick transition to milling.

The milling step will ensure the subsequent layers are flat but you will need a wax-supported model. This guarantees no extra support but expect many waste in the end. The Solid Ground Curing venture is not as prevalent as SLS or SLA. What is making it gain ground is the large, high throughput parts, which you can fabricate with more than just one 3D printing technology.

Solid Ground Curing Technology

Solid ground curing uses the common technique of coagulating of photopolymers by an entire lighting and solidifying of the whole surface, utilizing exceptionally arranged masks. In SGC process, each layer of the model is cured by presenting to an ultra violet (UV) light rather than by laser checking. So that, each part in a layer are at the same time cured and do not require any post-curing forms.

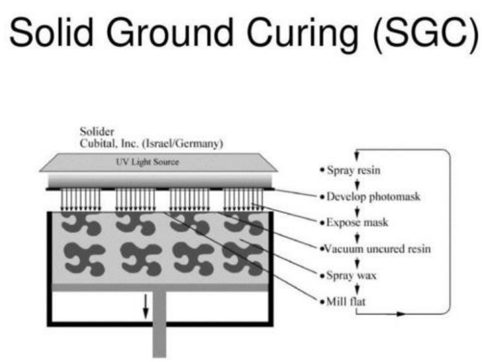


Image generated by GPL Ghostscript (device=pnmraw)

Solid Ground Curing Process

1. **Ascertaining cross segments**. You need ascertaining a cross segment of each cut layer in light of the geometric model of the part and the coveted layer thickness.
2. **Optical cover.** The optical cover is produced fitting in with each cross segment.
3. **Covering the platform**. In the wake of leveling, the stage is secured with a thin layer of fluid photopolymer.
4. **Mask positioning.** The cover relating to the present layer is situated over the surface of the fluid pitch, and the gum is presented to a powerful UV light.
5. **Residual fluid.** The lingering fluid is expelled from the work piece by a streamlined wiper.
6. **Filling voids**. A layer of softened wax is spread over the work piece to fill voids. The wax is then hardened by applying a cool plate to it.
7. The layer surface is trimmed to the coveted thickness by a processing plate.

8. **Covering work piece**. The present work piece is secured with a thin layer of the fluid polymer, and stage 4 to seven are rehashed for each succeeding upper layer until the point that the highest layer has been prepared.
9. **Melting**. The wax is liquefied endless supply of the part.

Advantages of Solid Ground Curing

1. **Solid Ground curing framework do not need a help structure.** No extra support is needed since wax is utilized to fill the voids.
2. **Accuracy of procedure.** The model created by Solid Ground Curing process is nearly precise in the Z-bearing in light of the fact that the layer is processed after each light-presentation process.

Disadvantages of Solid Ground Curing

1. **Too much waste.** In spite of the fact that it offers great exactness combined with high throughput, it delivers excessively waste.
2. **High operational costs.** Its working expenses are relatively high because of the frameworks many-sided quality.

Strong Ground Curing (SGC) forms are reasonable for building various parts with various geometries and measurements in clump creation of fast models; in any case issues in demonstrate precision, quality, and material properties of models restrict their applications. This is because it implores not just 3D printing but also other forms of printing technology such as:

- **Stereolithography (SD):** It is a method used to create 3-D printed objects. It uses a Stereolithography to convert liquid plastic into solid objects.
- Continuous liquid interface production
- Ultrasonic consolidation.
- Contour crafting
- Electron beam melting

There are different versions of solid ground curing. One for instance tons the whole procedure to just six steps:

1. **Spraying photosensitive resin.** You need using the Data Front End, Cubital’s software to create a CAD model. You have to spray the flat working surface when you start on layer creation steps.
2. **Developing the photo mask.** For each of the layers, you can produce a photo mask by using Cubital’s proprietary ionographic printing technic.
3. **Exposing the photo mask.** You will need a UV lamp for this to position the photo mask over your working surface. The UV lamp will help harden the exposed surface.
4. **Vacuuming uncured resin and solidifying remnants.** Once you are done curing, you need vacuuming all the uncured resin. This recycling will leave you the hardened areas intact.
5. Applying wax to replace uncured resin areas.
6. Mill the top surface flat.

Solid Ground Curing is diverse. The earliest signs are the number of 3 DS printing technologies that you can use. Cubital's software is well endowed, and it counters modernism in a way that makes it stay at the apex of ground curing.

LOM material

Laminated Object Manufacturing (or LOM) is a very fast and inexpensive way to 3D print objects in several kinds of materials. Sheets of material are bonded together and cut in the right geometry according to the 3D model. Laminated Object Manufacturing is mainly used for rapid prototyping processes, not for production.

LOM (Laminated Object Manufacturing): 3D Printing with Layers of Paper

There are a lot of different 3D printing processes available nowadays, but have you ever heard about Laminated Object Manufacturing? Laminated Object Manufacturing (or LOM) is a very fast and inexpensive way to 3D print objects in several kinds of materials. Sheets of material are bonded together and cut in the right geometry according to the 3D model. Laminated Object Manufacturing is mainly used for rapid prototyping processes, not for production.

MCor developed a paper based technology that allows multicolor 3D printing. Courtesy of MCor.

What is Laminated Object Manufacturing?

Laminated Object Manufacturing is a 3D printing method, developed by Helisys Inc (now Cubic Technologies). but what happens during this process? Layers of material, plastic or layers paper are fused, or laminated, together, using heat and pressure.

You may have never heard of this 3D printing technology before and that is normal. Even though this technique is efficient, affordable and quite fast, it is still not really popular.

In the LOM technology, the layered material is rolled on the building platform. Usually, the material is coated with an adhesive layer and the feeding roller heats in order to melt the adhesive. The layer is then glued to the previous one. A blade or a laser is used to draw the geometry of the object to build and draw crosses on the rest of the surface to facilitate the extraction of the final objects. At the end, the building platform contains a block composed of the final objects and the parallelepipoids that are to be withdrawn.

Objects printed using paper then taking on wood-like properties, and can benefit from a sand casting finish, while paper objects are usually sealed with a paint or lacquer to keep out moisture.

The technology has been brought to the public by Cubic Technologies (formerly Helisys inc.) that propose a plastic LOM machine. Recently, MCor launched their paper-based machine adding color to the technology.

What materials can be used with this 3D technology?

This technology is very versatile as almost any material can be glued. During this additive manufacturing process, layers of adhesive-coated paper, plastic, or metal laminates are successively glued together. The more common material used is paper as it is easily cut. Plastic can also be used, using a blade or a laser during the cutting stage. Metallic sheets are more unusual because the cutting stage is more complicated.

What are the particularities of this technology?

This is a very simple process making it easy to use, cheap and fast. The printing precision depends on the layer thickness and thus depends on the material. Compared to other technologies, it is not considered as very precise. The withdrawal of the support parallelepipoids is an exhausting and critical task that can lead to damaged objects.

What are the applications of Laminated Object Manufacturing?

LOM machines are mainly used for rapid prototyping plastic parts. Its low price and fastness make it convenient to make prototypes, even though the produced objects are far from end-use parts. Moreover, Laminated Object Manufacturing can't create really accurate models such as technologies like Selective Laser Sintering (SLS), or even Stereolithography (SLA). It is not possible to print intricate and complex geometries, but its cheap process and freeform fabrication process are making it a good prototyping technique.

Mcor technologies proposes a particular kind of LOM, they named this additive manufacturing process Selective Deposition Lamination (SDL). It is a paper based technology that adds color in the print. Sheets of paper are colour printed, selectively glued and cut with a blade. The glue is only applied in the surface corresponding to the object, then it is easier to excavate the final object. Plus, the addition of colour allows this technology to compete with binder jetting technologies to produce multicolor objects, even if the quality is not the same.

Are you looking for a great rapid prototyping technique? Check out our 3D printing materials catalog, and choose the best technology for your project! You will just have to upload your STL file on our online 3D printing service, we will manage your order with our professional 3D printers.

UNIT-6
SELECTION OF RP PROCESS

Selection of a RP system depend on several factors such as price accuracy, build envelope, build material, build speed, surface finish and type of application. Each RP system has its own strengths, limitations and application.

Rapid prototyping is the fast fabrication of a physical part, model or assembly using 3D computer aided design (CAD). The creation of the part, model or assembly is usually completed using additive manufacturing, or more commonly known as 3D printing.

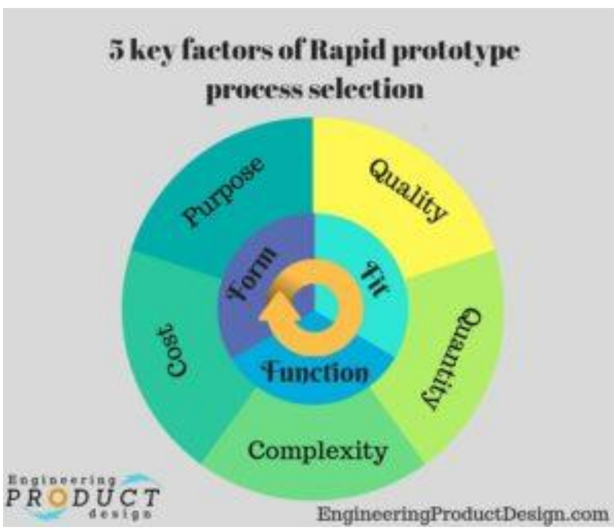
Selecting a Rapid Prototyping Process

The success or failure of a prototype depends on your selection of rapid prototyping processes for the new product development. There are various ways in which engineering product design prototypes can be made varying from simple cardboard mock-ups to fully machined metal sub-assemblies. Prototyping is crucial to any engineering product design, especially new product development. It is the process of making rough models of the product, for instance, to test its functionality, shape, size etc.

This article is about part-based prototypes i.e. how individual parts can be made to create the system level product prototypes.

5 key factors to consider when selecting a Rapid Prototyping Process

Prototypes vary in so many ways as each project, product and product design elements are different. As the success of any prototype will depend on the selection criteria of prototyping processes, these 5 key factors should be considered at the start of any prototype process selection.



5 key factors of rapid prototype process selection

1. Purpose
2. Quality
3. Quantity
4. Complexity
5. Budget/cost

Let's delve into these key factors to understand why they are essential in choosing your next prototyping process.

1. Purpose

Within an engineering product design and development project, prototypes are created for four purposes, according to Ulrich and Eppinger (2008). They are Learning, Communication, Integration and Milestones. These purposes of the prototyping will vary depending on which of the 4 new product development (NPD) stages you are in. Each stage of the NPD will have its feature and functionality requirement to eliminate risk. This will then define the fidelity type of the prototype required, which is the quality of the prototype discussed later.

First, it would depend on the **planned tests or risk mitigation exercises** such as test types, customer interaction feedback etc. If the product would go through rigorous testing, outside deployment and product verification then the material selection would play a key part in the selection of prototyping techniques.

Secondly, any **functional aspect y**ou would like on your prototype needs to be considered. Are you planning on functional tests or do you have any moving parts? This will dictate the selection and assembly.

Third, **changes and modifications.** It's highly unlikely that your prototype is going to be a success without a few tweaks. So, consider how easy or difficult it would be to modify to get the prototypes working.

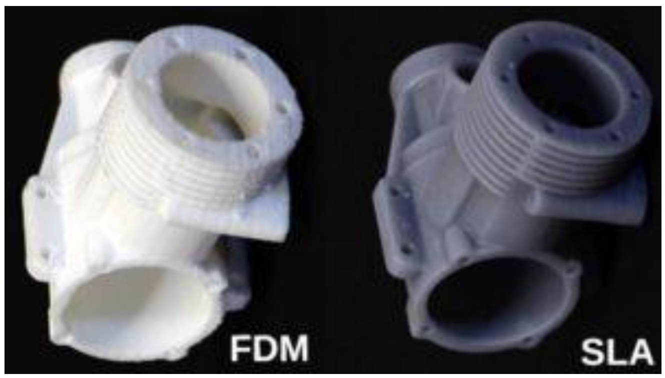
NPD stage

- **Product planning and clarifying task**
  - This stage generally requires very early proof of concept mock-ups, demonstration units and industrial design prototypes
  - Prototyping techniques
    - CNC machined foam models
    - Cardboard mock-ups
    - 3D printed parts and assemblies (FDM, SLA, SLS etc)
- **Conceptual design**
  - At this stage, you probably need scaled parts or assemblies of the design along with some user interface and limited functionally
  - Again, FDM parts are great at getting a feel for the shape and size. If you need more accuracy then you could move into the next level of 3D printing i.e. SLA, SLS and poly jet parts. If the parts are metal, then CNC at this stage is your best bet. In some cases, sheet metal fabrication is also worth considering
- **Embodiment design**
  - This is the development phase where you need to explore fully functional (form, fit and function) prototypes, hence details are important. At this stage, it is more than likely that the prototypes are going to be working assemblies containing a lot of parts
  - At this stage, you would also need more than one unit for testing purposes, and it is also worth considering the final manufacturing techniques so it could be simulated
  - Consider vacuum casting and high-resolution 3D printing such as SLS and SLA for plastic parts
  - SLM/DMLS parts ideal for simulating casting parts (Sand, investment and die casting)

- **<u>Detailed design</u>**
    - Any prototype made during this phase is more than likely to be used for functional testing and will also be for pre-production pilot runs
    - <u>Injection moulded parts can be prototyped using vacuum</u> casting while machined plastic parts can be 3D printed

2. Quality

- As discussed previously the **fidelity or the accuracy of the product** required will dictate what type of process and post-processing you would need. Quality of the prototype as compared to your final product or subcomponent also needs to be considered. As high-fidelity prototypes cost more, they should be considered in terms of return on investment.



Prototype qualities (credit:google images)

- For example, if you have a thread feature on a part then SLA is better than FDM but would cost more.
- **Life of the prototype** is also crucial when deciding the technology. For example, if the parts have fasteners that will be used frequently, then machined or metal inserts are a better option than 3D printed threaded or self-tapping holes.
- **Material selection** also plays a vital role in terms of the quality of the prototype. If the functional elements are linked to special material properties, such as surface finish and durability, then choosing additive manufactured parts might not be the best choice. The general material choices for the different manufacturing methods are as follows:

3d printing	**CNC**	**Vacuum casting**
Nylon, PLA, ABS, ULTEM, ASA, TPU	ABS, Nylon, Polycarbonate, PEEK	ABS, Nylon Nylon HT
Aluminium, Stainless Steel, Titanium, Inconel	Aluminium, Stainless Steel, Titanium, Brass	N/A

- If the prototype is made of more than one part, then the tolerance of the prototyped parts will have to be considered for ease of integration.

3. **Quantity**

- The number of required prototype parts are essential in deciding the process as some prototyping technologies are only cost-effective for smaller quantities. For additive manufacturing parts volume also plays a crucial part in costing as bigger parts will require more time to print compared to smaller parts. As a rule of thumb, the following rules apply.

Plastic parts

Prototype processes			
Plastic parts		Quantity	
		Low (1's)	Medium (10's)
Size	Small	3D printing	CNC machining (simple) 3D printing (complicated)
	Large	3D printing	Vacuum casting CNC machining

Metallic parts

Prototype processes			
Metallic Parts		Quantity	
		Low (1's)	Medium (10's)
Size	Small	CNC machining 3D printing	CNC machining Investment casting
	Large	CNC machining	CNC machining

4. **Complexity**

The complexity of the part and intricacy of the features will also dictate the rapid prototype process selection. Additive manufacturing is good for producing very complicated small parts, but one should be cautious about the final design because complicated means very expensive mass production.

Process	**Tolerance (mm)**	**Minimum wall thickness (mm)**
FDM	±0.20 – ±0.50	0.8 -1.0

Process	Tolerance (mm)	Minimum wall thickness (mm)
SLS/SLA	±0.20 – ±0.30	0.7 – 1.0
SLM/DMLS	±0.10	0.4 – 0.5
Binder jetting	±0.20	1.5 mm – 2.0 mm
CNC *	±0.012	0.5
Vacuum casting	±0.1	0.9 – 1.0

Please note that these tolerances and minimum wall thickness are typical values and hugely vary depending on the material choice and feature design.

AM complex parts

Parts that are eventually produced by injection moulding, various forms of castings can be prototyped using 3D printing while machined parts can be 3d printed or manufactured using conventional forming or subtractive manufacturing processes.

5. Cost

Finally, the resources available; the objective of the prototype would go hand in hand with the resources available. Time, money and man-hours need to get the prototypes manufactured and working, needs to be considered while choosing the prototyping technology.

Things to ponder:

- Most of the time, time consumed by post-processing or to get the part working from low-quality prototypes will be more than that of high-quality prototypes
- Some processes such as 3D printing might need some post-processing time but it’s relatively quicker and cheaper while a vacuum casting would give parts almost identical to that of injection moulding and can be used without post-processing. However, this will be more expensive with the tooling cost
- Cost of CNC is proportional to the complexity of the part while the cost of AM is directly proportional to the volume and size

- The overall cost would also be tightly linked to the quantities more for a process like CNC because of the higher set-up cost

Rapid prototyping selection process steps

- Define the purpose of the prototype
- Establish the level of approximation (quality and complexity)
- Outline the evaluation method and plan to identify quantities
- Ensure your cost is kept within your prototype budget

Issues in Rapid prototyping (RP)

Nowadays, rapid prototyping technology still faces many problems, most of which come from the level of development of the technology itself, especially in the following aspects.

1. Process Problem

The basis of rapid prototyping is the principle of layered superposition. However, what materials to layered superpose and how to layered superpose are need to research. Thus, people are try to study and develop new layered superposed molding method, in order to further improve the performance of the article and the forming precision and efficiency.

2. Materials Problem

Prototyping materials research has always been a hot issue. The properties of rapid prototyping material should meet:

1) Conducive to rapidly and accurately process the mold;

2) Must be close to the final usage of the part on the strength, stiffness, moisture resistance, thermal stability and other requirements.

3) Good for subsequent processing of the rapid molding.

Development of new RP materials, especially composite materials, such as nano materials, heterogeneous materials and materials of other methods difficult to make is still our direction of effort.

3. Accuracy problem

At present, rapid prototyping parts are generally in a horizontal accuracy of ± 0.1 mm, as well as the height (Z) direction accuracy. The basic principle of rapid prototyping technology determines that the process is hard to achieve the surface quality and accuracy specifications of those manufactured with conventional machining. Thus, it is an important way of improving rapid prototyping precision that integrated the basic theory rapid of prototyping and the conventional machining method, which makes them complemented each other.

4. Software Problem

At present, the hierarchical slicing algorithm used in rapid prototyping system is based on the STL file format conversion, which is to use a series of triangular mesh to approximate the CAD model data files. This data representation method has many defects, such as the loss of data caused by some gaps in the triangular mesh, the layered effect caused by plane delamination which reduces the surface quality and forming precision of parts. So now, we should focus on the development of new model slicing methods, like feature-based model direct slice method or the surface layer method, thereby reducing the error caused by the triangular approximation and improving the forming accuracy and speed.

5. Energy Problem

Currently, rapid prototyping technology uses light energy, thermal energy, chemical energy, mechanical energy and so on. In the energy density, the accuracy of energy control, forming processing quality, etc. still need to be further improved.

6. Application Area Problem

At present, the application field of rapid prototyping technology mainly lies in the new products development. The main purpose is to shorten the development cycle and get the effect of market feedback as soon as possible.

UNIT-7
RAPID TOOLING (RT)

Rapid Tooling

This chapter discusses how additive manufacturing can be used to develop tooling solutions. Although AM is not well suited to high-volume production in a direct digital manufacturing sense, it does have some benefit when producing volume production tools. This can be from the perspective of using AM to create patterns for parts that are required using materials or properties not currently available using AM or for longer run tooling where AM may be able to simplify the process chain. Commonly referred to as rapid tooling, we discuss here how AM can contribute to the product manufacturing processes.

Introduction

The term "tooling" refers in this case to the use of AM to create production tools. The tool is therefore an impression, pattern, or mold from which a final part can be taken. There is a variety of different ways in which this can be achieved and these will be discussed in this chapter.

In recent years, as can be seen from other chapters in this book, there has been a tendency to attempt to use AM for production of parts directly from the machine. This is the so-called Direct Digital Manufacture (DDM) and there are numerous reasons why this can be a preferable approach to production. However, there are still a number of reasons for creating tooling rather than DDM:

• The larger the number of parts produced; the more cost-effective it may be to make a production tool, provided it is known how many parts can be made using such a tool.
• The material requirements for the final part may be very specific and not currently available as an AM material but may however be possible through the tooling route.
• It may be that the product developer wants to understand the tooling process and thus use AM to create a prototype tool.
• This may actually be the quickest and most effective way to create the tooling according to the required specifications. This may be particularly relevant where short lead-times are important.

Tooling is often broken up into two types, referred to as "short-run" and "longrun" tooling. Although discussed in numerous articles like those by Pham and Dimov, there are no specific definitions for either of these. Therefore we will attempt to distinguish them here.

Short-run tooling may also be referred to as prototype tooling or soft tooling. The objective is to use techniques that achieve a tool quickly, at low cost and with few process stages. Quite often there are a number of manual steps in the process. It is understood that only a few parts are likely to result from use of the tool; possibly even just one or two parts up to around 100 or more. Every time the tool is used, it should be inspected for damage and viability. It may even be possible (or necessary) to repair the tool before it can be used again. It should be noted that if a tooling solution is required in a very short time (say in a few days), then AM-based short run tooling may be the only way to arrive there.

Long-run tooling has greater emphasis on use of tooling for mass production purposes. Some injection molding tools can last for years and millions of parts. Although wear is always going to occur, the wear-rate is very low due to the relative hardness of the tool compared with the resulting parts that come from them. The processes required to create long-run tools from AM would still be chosen for their relative cost and lead-time, but in this case they are more likely compared with conventional (subtractive) manufacturing processes. Almost every AM-based long run tooling solution is likely to involve a metal fabrication process.

The benefits of using a rapid tooling solution may be difficult to determine, but could be immense. Very rarely is a product created from a single tool and the more complex the product, the more difficult it is to plan. Consider the problem of bringing a new mass-produced car to the market. Some parts will already be available; some existing parts may require redesigning while others will require design from scratch. Some of these new parts will be relatively simple, while others will have significant performance specifications that could have very long lead times. Now consider how you would create a plan to bring all these together so that the car is launched on schedule. Even the manufacture of a very simple part could delay the whole process. The use of AM-based short-run and long-run tooling can be extremely beneficial because of the short reaction times and simplified process chains. A car manufacturer may be able to plan more easily and react to disturbances in the process chain more efficiently. Even tooling that does not last very long (or, for that matter, DDM) can be used to bridge the gap to long-term tooling made using conventional methods. Delivery times can be met even though the entire mass production facility has yet to be completed.

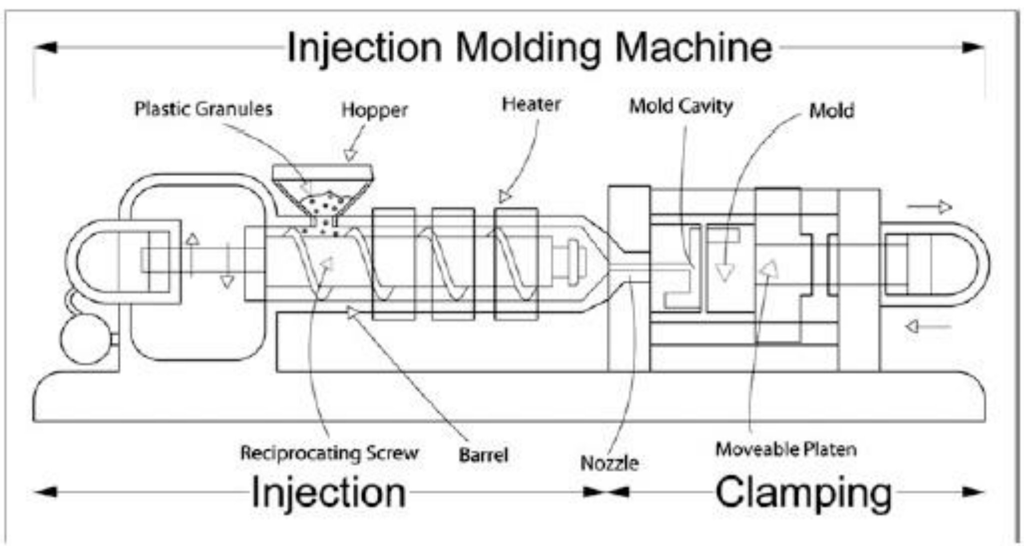
The majority of rapid tooling solutions are focused on the creation of injection molding (IM) tooling. This is because there are a huge number of products made 438 18 Rapid Tooling from polymers using this approach. We will go on in this chapter to discuss how we can directly fabricate IM parts using AM as a replacement for subtractive machining processes. Electron discharge machining (EDM) is an alternative to the more conventional abrasive metal cutting that is worth separate consideration in this chapter. Of course, not all products are made from polymer parts. There is a huge variety of metal, ceramic, and composite-based materials and related manufacturing methods. One method that fits very well into an AM process chain is investment casting, which we will discuss here, followed by some less mainstream AM-based approaches that have found niches for some manufacturers.

Direct AM Production of Injection Molding Inserts

Wikipedia describes injection molding as the most common modern method of manufacturing parts and that it is ideal to produce high volumes of the same part. The general principle is quite straightforward in that molten polymer is forced into a metal mold. Once the polymer has cooled and solidified, the mold splits open to reveal the part which is then ejected and the process repeats. There are many texts that cover IM in varying levels of detail. An excellent online resource can be found from Bolur. From these we can see that, similar to many processes, optimization and maximization of the output from IM can be very complex. As our demand for higher throughput, performance, quality, etc. increases so will the need for more cost-effective solutions.

Since the IM process requires a mold that can somehow separate for the part to be removed, there are a number of issues that require attention:

• A simple mold will have a cavity into which the polymer is injected. A core will form the other side of the mold, which is removed after the cooling process so that the part can be ejected. A mechanism (usually a set of ejector pins) is engaged to push the part out from the cavity. However, for this to be effective, the cavity walls usually have a slight slope (referred to as a “draft angle”) that reduces shear forces between the polymer and the mold that would cause the part to stick.
• Not all molds can be easily split into a simple core/cavity to reveal the part. Complex geometry parts may require mold sets that separate into more than two segments. Parts may require very careful redesign so that the number of mold components is minimized. Even so, mold sets can be very complex.
• Filling the mold with molten polymer can also be problematic. The mold must be completely full before it starts to solidify, else there may be cavities. Parts that comprise many features, like thick or thin walls, ribs, bosses, etc. must be carefully analyzed to ensure the mold set is properly filled. Very complex parts may require multiple injection and venting points to ensure effective mold filling as well as fine-tuning of the temperatures, pressures and cycle operations within the IM machine. There are numerous softwares available for
mold operation analysis, like Moldflow.



A simple IM machine setup as drawn by Rockey

An IM machine has a standard plate set into which mold sets are inserted. For these inserts, it is necessary to know where to locate the injection point, the ejector pins, risers, and other features that comprise a fully functioning mold solution. It is these inserts that effectively “customize” the process and where AM can therefore contribute towards a solution.

Inserts can be made using either metal or polymer AM technology. Polymer inserts are obviously less durable, but are much quicker and cheaper to make. In a white paper published by Stratasys, the Polyjet process was demonstrated to be effective for producing inserts for a variety of applications .

IM applications have been tested using the standard Polyjet materials. Best results were presented for the Digital ABS material. Parts were made in a conventional IM machines using a variety of materials, including polyamide, ABS, and polyethylene at temperatures up to 300 _C. Up to 100 cycles have been observed before the inserts broke. Similar results have been reported using SL and polymer laser sintered parts. It is important to note that the IM inserts made this way should be handled carefully so that they can achieve acceptable results. Even though the IM process operates above the heat deflection temperature for the AM materials, it is still possible to get acceptable molded parts. This is possible if the IM cycle is lengthened so that the parts can cool more inside the mold before separation and ejection. Note that this only really works for relatively simple core/cavity sets. For this type of application, the costs can be around half of similar aluminum molds, with significant reductions in lead-time. One can expect some hand-finishing of the resulting molded parts.

A core/cavity mold set showing a central injection point and channelling to regions where 5 different parts are formed in one cycle

Polyjet inserts for a two cavity mold set, showing a close-up of the ejector pins (courtesy Stratasys)

The primary concerns when making mold inserts using polymer AM are heat deflection, wear, and accuracy. Most AM processes can provide partial solutions to these problems, but generally the most accurate processes have low heat deflection temperatures and the highest temperature materials can be found in lower accuracy processes. A number of attempts have been made to develop materials for IM inserts with polymer AM processes. One material of note is the copper-polyamide material that was developed for the polymer powder bed fusion process. Adding a copper filler to the polyamide matrix material served to improve the heat transfer away from the surface when a mold is used in the IM machine. The copper also provided additional wear resistance, which increases the life of the mold. It is interesting to note however that this is not a widely used material as the copperpolyamide is not very useful for many other applications so only appropriate where a large number of these molds are needed.

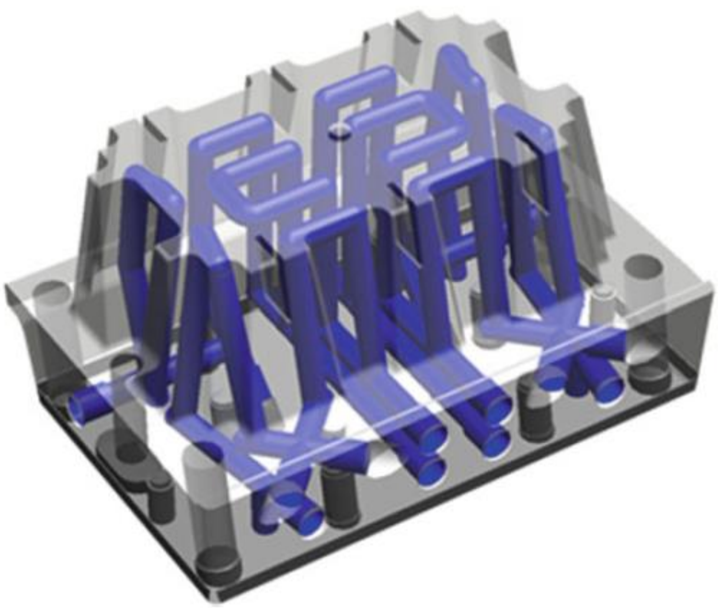
A number of chapters in this book discuss AM of metal parts. One of the initial drivers for this technology was for IM mold inserts. AM can provide a near-net shape for the metal inserts. Several materials have been developed for metal AM that could be used for this, but the most widely used would be H13 tool steel. Almost every process that can achieve this is based on powder metal sintering. Near-net shape can be achieved up to an Ra surface roughness of 12–20 μm but this would generally not be acceptable for most applications and machining of the parting surfaces in particular would be necessary. If the mold surface also requires machine finishing, then very careful attention must be given to gaging so that all of the original part lies outside of the machining volume. Incorrect gaging could lead to some regions not having sufficient stock material to achieve an adequate surface. It is therefore common for designers to add material to the CAD model as a machining allowance. Figure shows a tool set where the inserts were made using a powder metal system, with two parts that were molded from them.

Early metal powder AM machines were very expensive and suffered from problems with accuracy and consistent material properties. At that time there were a few alternative approaches to creating metal parts in the Rapid Steel and KelTool processes. While these approaches have become virtually obsolete, there was distinct advantage in that these processes could result in a fully metal part but using a conventional polymer AM machine. However, there was the need for additional furnace technology that added to the expense of the process.

Powder sintering could also be used to create parts that are a blend of polymer and metal powders. The polymeric material acts as a matrix that can hold the metal powder in place. The use of a high thermally conductive metal powder, like copper, would be the most ideal to use for the purpose of creating IM tooling inserts. The copper would cause heat energy to conduct away from the matrix polymer, thus allowing more rapid cooling during the IM process. The copper powder, being harder and more durable than the polymer, would also enable longer tool life.

One significant benefit to the use of AM for creation of injection mold tooling is the capability of creating conformal cooling channels. It is normal to run coolant through the IM inserts, facilitating the cooling of the plastic part following the injection of the molten polymer. This cooling process is very dependent on the geometry of the part being molded, with larger voluminous segments cooling slower than smaller, thinner sections. Greater flow of coolant close to the larger segments can enable faster and more regular cooling, which can also improve the part quality by preventing part warpage due to thermally induced stress. The geometric freedom that is a characteristic of AM can enable very complex cooling channels to be designed into the part. While the best way to achieve such conformal cooling is very much open to debate, benefits have been catalogued. An example of conformal cooling can be seen in Fig. Note that this approach can be applied to both short- and long-run methods.

A direct metal laser sintered tool set, with two parts that have been molded from them



A tool insert design, showing the location of conformal cooling channels

EDM Electrodes

A number of attempts have been made to develop EDM electrodes by plating AM parts [10]. These electrodes could feasibly be used for die-sinking EDM for creating cavities for IM application. The most common method of plating the polymer AM parts would be by using electroless plating of copper. There are two major drawbacks to this plating approach. The first is that electroless plating is best suited to plating a thin layer of material on a surface. For EDM however, the electrodes are more effective with a thicker amount of conductive material deposited. It is difficult to deposit sufficiently thick material in a quick and easy manner and with controllable thickness. This leads to the second problem, which is that even if you can deposit sufficient material, the definition of the electrode will be compromised by this excessively thick layer of material. Although possible, it is not a very effective method of making electrodes.

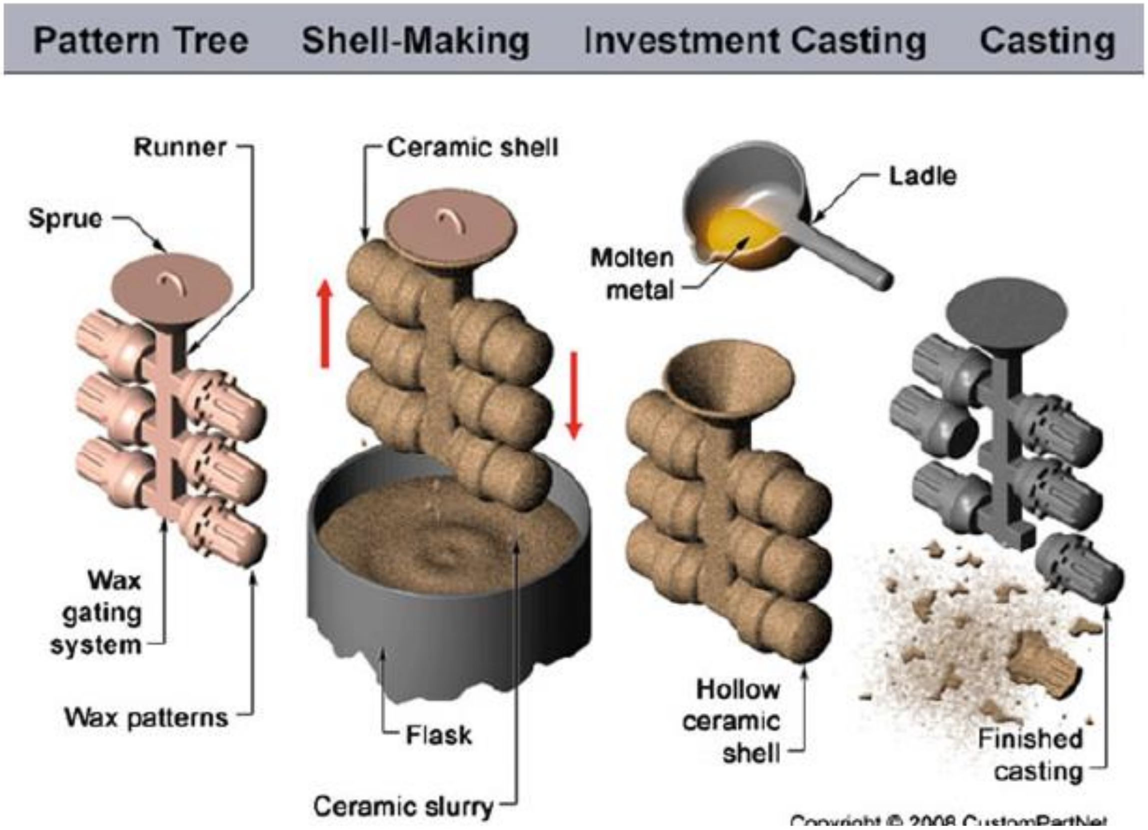
While it may be possible to create an electrode using powder metallurgy methods from AM molds, possibly a more effective method would be to use direct metal fabrication. Stucker, et al. used this approach to create electrodes using Zirconium diBoride (ZrB2). This material was encapsulated in a copper matrix material, which was melted using a selective laser melting approach. The resulting metal matrix composite was observed to have good erosion characteristics, wearing approximately 1/16th the rate of a pure copper electrode.

Neither of the above approaches has achieved popularity and there appear to be much better ways of creating EDM electrodes. However, recent improvements in metal powder melting systems may revive this research and development since electrode production can account for a significant amount of the manufacturing costs.

Investment Casting

Investment casting is the process of generating metal parts from a nonmetal pattern. Figure efficiently describes the investment casting process. The patterns are in some way assembled into a structure that can be coated with ceramic to produce a shell. The ceramic starts as a slurry into which the structure, referred to as a “tree” for obvious reasons, is dipped to produce a closely forming skin. Once this has dried, it is strengthened by applying more coats until it is strong enough to withstand the casting process. Prior to casting, the pattern is removed by burning out the material. Care must be taken at this stage to ensure all the material has been burned out of the shell, leaving no residue. The ceramic shell can withstand the high temperature of molten metal during the pouring process, which can then be left to cool before the shell is broken from the tree. The metal replicas of the original pattern are cut from the “trunk” of the structure prior to post-treatment.

The great advantage of this is that parts can be made in a wide range of materials, specific to the application. While powder metal AM systems can produce parts directly in metal, there is a much more limited range of metals available. Furthermore, this is an approach that can result in metal parts from a nonmetal AM technology. A number of AM processes are capable of directly making parts in wax, including material jetting and material extrusion. However, it is also possible to make investment casting patterns from other materials, including polycarbonate and ABS, which are available from a wide range of AM machines. The key is to ensure that the material does not expand rapidly during the burnout process, prior to the metal casting. One way to achieve this is to apply the honeycomb core approach, such as the SL QuickCast build style, rather than using a solid fill.



Schematic of the investment casting Process

UNIT-8
DIRECT RT PROCESSES

Direct Methods of Rapid Tooling

All of the previous methods of rapid tooling involve the indirect production of a master pattern from which the tool is produced. One of the concerns of producing a tool is the time it takes to produce and finish this pattern. Also, replication techniques, such as these can lead to inaccuracies. Ultimately, companies want to produce the tooling directly, although most of the direct tooling methods are not without limitations.

Using additive "layer manufacturing" techniques, it is possible to include additional features in the tool that are impossible to achieve with conventional tooling techniques. The most significant of these is conformal cooling (or heating) channels that allow the cooling or heating of the tool at points where it is required – not only where the channels can be conveniently drilled, as in conventional cooling. Investigations have shown that conformal channels can cut injection mold cycle times by up to 40 percent.

1.Direct AIM tooling

Rather than making a master stereolithography pattern around which a material is cast, it also is possible to build the cavity directly on the stereolithography machine. 3D Systems (Valencia, CA) has named this process Direct AIM. (AIM stands for ACES Injection Molding. ACES stands for "Accurate Clear Epoxy Solid," which is a stereolithography build style.) Although not nearly as strong or hard as conventional tooling, it is possible to inject a range of thermoplastics into these cavities and produce useable parts. At present, only less abrasive and lower melting point polymers are being molded, although research is underway to improve this application.

Stereolithography tools are generally produced with the standard commercially-available stereolithography resin. Up to 500 parts have been molded from a single tool, although 10 to 50 parts is more typical. Research into the development of high temperature and filled resins also is being undertaken by several organizations.

The process is quick and it produces parts using production thermoplastics. Low tool strength and the risk of failure are disadvantages.

2.SLS RapidSteel

In the same way that a cavity can be generated directly by stereolithography, it also is possible to build tool cavities directly using the laser sintering process. With DTM's RapidSteel (also referred to as RapidTool), digital models of the core and cavity geometries are created and sent to a Sinterstation machine for fabrication in RapidSteel powder. This material consists of particles of mild stainless steel that are coated with a thin layer of a polymer binder material. The Sinterstation produces green parts that are then fired in a furnace. The furnace removes the polymer binder and infiltrates bronze into the mold inserts through capillary action. This process produces a fully dense tool that consists of about 60 percent steel and 40 percent bronze. The inserts are then finished, drilled for ejector pins, and fit to a mold base.

The process produces a durable mold that can be used for injection-mold tooling, as well as die-casting applications. RapidSteel molds have been used to cast hundreds of aluminum, zinc and magnesium parts. The process allows for complex geometries and RapidSteel molds can withstand the conditions of injection molding. However, RapidSteel requires finish machining and polishing that can be time consuming

The advantages are speed, good tool strength and its use for injection molding and die-casting. Disadvantages are equipment cost and size limitations.

3.Copper Polyamide Tooling

The Copper Polyamide tooling process from DTM (Austin, Texas) involves the selective laser sintering of a copper and polyamide powder matrix to form a tool. All of the sintering is between the polyamide powder particles.

The process boasts an increase in tool toughness and heat transfer over some of the other soft tooling methods. These characteristics are provided by the copper and can give the user the benefits of running a tool with pressure and temperature settings that are closer to production settings. The primary disadvantage is the low material strength.

4.Direct Metal Laser Sintering

Direct Metal Laser Sintering (DMLS) from EOS involves the direct processing of metal powders in a laser sintering machine. Typically, the machine is used for the production of tool inserts, but it also is possible to produce metal components. Two materials are available for the DMLS process: 1) bronze-based materials, which are used for injection molding of up to 1,000 parts in a variety of materials, and 2) steel-based material, which is useful for up to 100,000 plastic injection molded parts.

This process was used to produce injection mold tooling for a Germany appliance manufacturer. Seven mold inserts were produced in 20 hours using the bronze-based material. Several thousands molded parts were produced in 30 percent glass-filled polyamide. The tool took two weeks to produce compared to 10 weeks for a machined tool and cost about $6,800 compared to $8,200 for the machined tool.

DMLS offers good feature definition, although the surface definition of the steel-based powder needs improving. Also, the steel material builds slowly.

5.Laminated Tooling

Laminated tooling is an alternative to building cavities directly on an RP machine. Using the similar principles to the Laminated Object Manufacturing (LOM) process, layers of sheet metal are cut to replicate slices through a CAD model. Laser cutting or water jet technologies generally produce the profiles.

To produce a mold tool, the CAD model must take the form of the required cavity. By cutting all of the slices of the cavity in sheet metal, a stack of laminates can be made to replicate the original CAD model. Using either clamping or diffusion bonding, it is possible to create a pseudo-solid cavity in hardened tool steel without the need for complex post process cutter path planning. Due to the use of relatively thick laminates – typically 0.040 inch (1 mm) – the surface finish of the tools is generally poor; therefore, some form of finish machining is generally required.

Laminated tools have been used successfully for a variety of techniques including press tools, blow molding, injection molding and thermal forming. Research also is being performed into the use of laminate tools in pressure die-casting. Tool life is a function of the initial sheet material, which can be hardened after cutting and lamination. However, part complexity is bounded by layer thickness.

One significant advantage of laminated tooling is the ability to change the design of parts quickly by the replacement of laminates (if un-bonded). Conformal cooling channels also are easily incorporated within the tool design and laminated tooling is good for large tools as well. The need for finish machining to remove the stair steps is the main disadvantage of this process.

6.LENS

The Laser Engineered Net Shaping (LENS) system from Optomec (Albuquerque, New Mexico) –originally developed at Sandia National Laboratories – builds parts using a metal powder feed into a laser, essentially laser cladding. The LENS process injects metal powder into a pool of molten metal created by a focused Nd:YAG laser beam. The fabrication process occurs in a low-pressure argon chamber for oxygen-free operation. A motion system moves a platform horizontally and laterally as the laser beam traces the cross-section of the part being produced. After forming a layer of the part, the machine's powder delivery nozzle moves upward prior to building the next layer.

Like other RP techniques, LENS is an additive fabrication method – although it produces fully dense metal parts. To date, parts have been fabricated in 316 and 304 stainless steel, in nickel-based super-alloys such as Inconel 625, 690 and 718, H13 tool steel, tungsten, Ti-6Al-4V titanium alloy and nickel aluminides.

The primary advantage is 100 percent dense parts. The disadvantages are poor surface finish and small feature definition.

7.Controlled Metal Build-up (CMB)

Albrecht Röders GmbH & Co KG (Soltau, Germany) has commercialized a process called Controlled Metal Buildup (CMB). The basic technology was originally developed at the Fraunhofer Institute for Production Technology – IPT (Aachen, Germany). Last year, the company sold three systems.

The process involves laser cladding and milling that results in 100 percent dense parts. CMB deposits the material from a steel wire and a 1-2 kW HDL laser welds the steel onto the surface of the work piece. A high-speed cutter flattens each layer before a new layer is deposited.

8.Prometal

ExtrudeHone's (Irwin, Pennsylvania) ProMetal Rapid Tooling System – named RTS-300 – is the commercial realization of MIT’s Three Dimensional Printing (3DP) process for manufacturing metal parts and tooling.

The machine is capable of creating steel parts up to 12 ´ 12 ´ 10 inches (300 ´ 300 ´ 250 mm) in size. ProMetal applications include tooling for plastic injection molding, vacuum forming, blow molding, lost foam patterns and the direct fabrication of powder metal components

ExtrudeHone sold its first commercial RTS-300 to Motorola, which was installed in early 1999. Motorola joined a collaborative effort consisting of several industrial members, all part of MIT's Three Dimensional Printing Consortium. Although early reliability problems delayed the implementation effort, recent advances have provided acceptable results.

Many rapid tooling methods are available. Most of them require a master pattern, although a growing number offer a direct path to fabricating the tooling. In the short term, indirect methods of RT will continue to flourish because these methods are the most developed. However, in the long term companies will lean toward direct methods of tooling because they eliminate a step – the use of a pattern – that can help reduce the time it takes to produce the tooling and improve the accuracy of the process.

The demand for faster and less expensive tooling solutions has resulted in an impressive number of RT methods being developed worldwide. Many companies are pursuing the development and commercialization of RT because of its market potential. Each of the processes comes with a set of strengths countered by limitations. Typically, this results in solutions that cater to niche applications. Yet, because of their possible impact, these developments are causing a flurry of inquiries from companies in the Americas, Europe, Asia and other developed regions. Meanwhile, countless manufacturing companies are working hard to determine if the time is right to phase in one of these approaches.

Indirect Methods of Rapid Tooling

Several pattern-based processes have been developed for creating a mold rapidly, with varying costs, leadtimes and process capabilities. The accuracy of these processes depends in part on the accuracy of the RP process used to create the pattern.

1.RTV Silicone Rubber Molds

One of the most popular tooling applications for RP is the production of room temperature vulcanizing (RTV) silicone rubber molds. Silicone is a versatile material (although somewhat expensive) that can be molded around a master pattern to produce a cavity. With the advent of rapid prototyping techniques, master patterns are often an RP model. Silicone rubber molds are used to produce urethane or epoxy prototypes.

The process of making a rubber mold consists of making a master pattern, finishing the pattern to the desired appearance and casting RTV silicone rubber around the pattern to form the mold. Using the transparent material the model is suspended within a box and silicone rubber is poured to fully surround the model. After the silicone rubber has solidified, the parting line is cut with a scalpel and the model removed, leaving the required cavity.

It is then possible to mold two-part thermoset materials within the cavity. One of the most popular is polyurethane, which is available in a variety of mechanical properties and can mimic the mechanical and thermal properties of elastomers, ABS, nylon and other popular thermoplastics. Polyurethane is usually poured into the silicone rubber cavity under vacuum to avoid air bubbles in the molded component. The silicone rubber tool will generally produce about 20 polyurethane parts before it begins to deteriorate. This will depend on the amount of detail in the tool and the type of polyurethane being molded. Flexible polyurethanes require longer post cure times within the mold, which is placed in the oven at 149° F (65° C). This prolonged contact dries out the surface of the silicone rubber and renders it more brittle. Once this occurs, fine detail on the inner surface of the mold starts to break off and subsequent molded parts reflect this loss.

Silicone rubber tooling provides fast, inexpensive molds, excellent part cosmetics, and the option of using multiple materials. The process is suitable for small or large parts. The primary weakness of the process is that the properties of the urethane materials are different from those of the thermoplastic materials used in production. Due to material cost and labor demands, individual part prices are relatively high.

Even with its limitations, silicone rubber tooling can be used as a production process. Bastech (Dayton, Oh) currently uses silicone rubber tooling to make an instrument case that has high cosmetic requirements, including texture, but very little strength requirements. In this project, the customer required only 100 parts per year. Measuring 350 x 300 x 20 mm (14 x 12 x 2 inches), the case would have required a significant investment in hard tooling.

2.Vacuum Casting

Plastic parts are vacuum cast by placing a silicone tool in a vacuum chamber with a polyurethane resin. The two-part resin is mixed and de-gassed before being poured into the silicone cavity. After pouring, the vacuum is released and the tool is removed to a post-curing oven for up to two hours depending on tool size. Following an exothermic reaction of the two-part resin, the cavity is opened and a polyurethane part removed. The silicone cavity is then closed and the process repeated.

3.RIM

Unlike vacuum casting, the Reaction Injection Molding (RIM) process does not rely on expensive vacuum chambers and mixing units. The process uses a simple resin injection system with two pressurized chambers. Using an injection nozzle, a silicone tool is filled at atmospheric pressure until excess resin is driven up through a series of riser holes. The cure reaction time is much shorter than in vacuum casting. There is no thermal cycling and the contact time between the resin and silicone rubber is much shorter; therefore, the tools can last for up to 100 shots.

4.Wax Injection Molding

In addition to two-part resin molding, silicone cavities also are suitable for low-pressure injection molding of waxes for investment casting. Using a low pressure, injection system, semi-molten wax is forced into the silicone cavity until full. The cavity is then chilled until the wax has fully solidified. The wax is then removed from the cavity and the process repeated. However, due to the fragility of the investment casting wax material, extreme care must be exercised when removing wax parts from the silicone tool.

The advantages of RTV silicone rubber tooling is that it is quick to produce, reproduces detail impressively well and it's fast for producing a limited number of plastic parts. Disadvantages are poor tool life, cost of silicone rubber and lengthy cycle time. Also, it does not use the final production material (except for wax) or final manufacturing process.

5.Spin-Casting

An interesting application of silicone rubber as a mold material is available from a company named Technicast Moulds Ltd. (Watford, Herts, England). The tools used in this process are made from vulcanized rubber with several models located in a radial fashion in a disc-shaped tool. This process makes it possible to cast polyurethane or zinc-based alloys. To aid in the filling of the cavity, the tool is rotated so that the centrifugal force pressurizes the cavity.

This is an ideal process for forming small zinc castings that will ultimately be produced by die-casting. If handled carefully, spin-cast tools can produce in excess of 100 replicated parts before degradation of the tool. Parts also are produced in a range of low melting point alloys.

The advantages of spin-casting include the option of processing a variety of materials that range from polyurethanes to zinc; the process is relatively quick and the equipment is relatively inexpensive. Disadvantages include size limitations, the fact that it is not a production process and the mechanical properties of the zinc castings are not the same as with die-casting.

6.Cast Resin Tooling

This is one of the simplest and most economical methods of producing a tool for the injection molding of thermoplastic parts. It consists of mounting a pattern within a mold box, setting up a parting line, and then painting and later pouring resin over the pattern until there is sufficient material to form one half of the tool. After completing the first half, the process is repeated for the other half of the tool. There are many tooling resins available with different mechanical and thermal characteristics – with epoxy being one of the most popular. The resins are often loaded with aluminum powder or pellets to improve the thermal conductivity and compression strength of the tool and to reduce the cost of the resin. Cast resin tools are usually used for 100 to 200 molded parts, although it's possible to get up to 1,000 parts – depending on the material being molded.

The advantages of this process are that it's fast, relatively simple, and can be used to mold common thermoplastics such as polypropylene and ABS. A disadvantage is the low mechanical strength of the molds, especially when the mold includes small thin features. For this reason, this method of rapid tooling is only suitable for relatively simple shapes. Also, the low thermal conductivity of the mold material lengthens the molding cycles times.

7.Spray Metal Tooling

Metal spraying is used for the production of soft tooling. It involves spraying a thin shell of about 0.080 inch (2 mm) in thickness over a pattern and backing this with epoxy resin to give it rigidity. Several metal spraying techniques are available. With most RP techniques, the models produced have a low glass transition temperature (i.e., the temperature where the material starts to change to a soft amorphous structure). Therefore, it is important to keep the pattern temperature as low as possible when spraying. If the temperature of the model increases sufficiently it will start to relax and distort, which results in an inaccurate tool.

The most popular techniques for use with RP models are spraying low melting point alloys (lead-/tin-based) with a gun similar to a paint sprayer and metal deposition with an arc system. The arc system feeds two wires into a gun and an electric arc is struck between them. This causes the wire material to melt and then a compressed gas atomizes and sprays it onto the pattern. The higher the melting point of the wire material, the more difficult it is to keep the pattern cool. Therefore, it is common to spray zinc or aluminum based alloys directly onto RP models. It also is possible to spray higher melting point materials onto RP models, but it is necessary to be a little devious. One technique is to apply a metallic coating by using electroless plating or physical vapor deposition. Once there is a metallic coating on the model, heat will be transmitted more readily across its surface.

One problem associated with metal spraying is that it produces shells with high internal stresses. It is possible to counteract these by simultaneously shot-peening the sprayed shell. Steel shot fired at the shell during spraying induces compressive stresses that counteract the tensile stresses.

Metal spraying is typically used on models that have large gently curved surfaces and is indeed most suited to this type of geometry. It is very difficult to spray into narrow slots or small diameter holes. When these types of features are included on the model, it is common to make brass inserts, locate them in the model and spray around them. When the model is removed from the shell, the inserts are permanently fixed into the shell. These inserts also are stronger than the shell material, which is weak and breaks easily if formed as a tall, thin feature.

Spray metal tools can produce more than 1,000 parts depending on the process, material being formed and the amount of tender loving care given to the tool. Clamping and injection pressures for metal-sprayed injection tools are usually less than those for steel or aluminum tools and may affect the mechanical properties of the injection-molded part. And because the shell is very thin and generally backed up with an epoxy-based resin, the thermal conductivity of a metal-sprayed tool is less than that of an aluminum or steel tool. This also will affect the mechanical properties of the injection-molded components and will increase cycle time. Some plastics are much more corrosive and abrasive on tool faces. This can be partially overcome by a variety of techniques, such as plating the tool surface with nickel or chrome, or using aluminum or steel inserts.

Spray metal tools have been used in many applications including sheet metal forming, injection molding, compression molding, blow molding and pre-preg sheet lay up. Various plastics have been molded including polypropylene, ABS, polystyrene and difficult process materials such as reinforced nylon and polycarbonate.

The main advantage of spray metal tooling is that you can produce large tools quickly. The main disadvantage is that it may be difficult or impossible to spray into narrow slots or deep holds – meaning that the part geometry must be relatively simple. Molds are not particularly strong and the process requires special equipment and special operating environment.

8.Sprayed Steel

The Sprayform sprayed steel process is similar in method to traditional sprayed metal tooling, in that atomized material is deposited using a spray gun. However, the main difference is in the mechanization of the process, as multiple spray heads are involved. The process produces much harder tools and is therefore a much more useful process than traditional sprayed metal tooling

The Ford Motor Company (Dearborn, Michigan) has purchased the technology behind the sprayed steel process, which was developed by Sprayform Holdings Ltd. of the UK. Currently, Ford is licensing the process to other companies.

The primary advantage of the Sprayform process is that it works well for large tools, especially as sheet metal stamping dies. It offers a high deposition rate and is less expensive compared to conventionally machined steel tooling. The cost of the equipment and the licensing fees, as well as the limitation of spraying into holes and slots are disadvantages.

9.Rapid Solidification Process

Another steel spray process is currently in development at Idaho National Environmental and Engineering Lab (INEEL) called Rapid Solidification Process (RSP). It differs from other sprayed metal processes in that it can deposit hundreds of pounds of material per hour, while the conventional wire-feed systems deposit approximately 15.4 lbs. (7 kg) per hour. This means that, potentially, the RSP process could be used to build the entire tool as opposed to a thin shell that requires back filling.

Global Metal Technologies, Inc. (Solon, Ohio) has entered into a Cooperative Research and Development Agreement (CRADA) with INEEL (Idaho Falls, Idaho) and intends to use RSP tooling in its production facility. The company claims that RSP tooling lasts 20 percent longer than conventional dies and can lower tooling costs by 20 percent.

INEEL has been successful in spraying H13 and P20 tool steels onto a ceramic take-off of an RP master pattern. A limitation at present is the size limitation of about six inches (150 mm).

10.Plaster Molds

Plaster mold casting is a prototype manufacturing process for simulated die-castings. Although there are several variations of this process, it usually begins with a master shape of the die-casting. It is not absolutely necessary to include draft in the walls at this stage, but it can help. A silicone rubber reversal is then molded over the master. A second silicone rubber is molded into the first. This provides a silicone rubber positive of the original model. Plaster is molded around the second silicone rubber positive to provide a plaster cavity. Metal is poured into the plaster cavity. After solidification of the metal, the plaster is broken away.

The rubber version of the master is required so that it can easily be withdrawn from the plaster mold. It is also possible to mold epoxy off of the master and pour plaster over this. The epoxy molds will have a greater life than those made from rubber.

Typical leadtimes from the manufacture of the master model to manufacture of 10 castings is about 8 days, and two weeks to produce 30 to 50 castings. However, three to four weeks is a more typical delivery time. The cost of prototyping with this process is about two to five percent of the cost of a production die, so it is considered to be a good insurance.

The advantages of the process are low mold cost and good surface detail. Also, it's possible to produce reasonably large parts with this process. One disadvantages is lower cooling rates, which means poorer mechanical properties. This can lead to parts with a yield strength that is 20 percent lower than conventional die-casting. Another disadvantage is that you must produce a new mold for each casting. And finally, slightly different alloys are used for plaster casting compared to die-casting

11.Electroforming

Electroforming involves electroplating a thick shell (several millimeters thick) onto a master pattern. Before plating can commence, the surface must be made electrically conductive. A simple technique to achieve this is to spray a conductive lacquer onto the model. After plating, the shell is removed and then backed with a suitable material.

This is a technique used to produce tools for shoe soles with complicated patterns from original wax models. Nickel is a common material for electroforming and has good thermal conductivity and strength. The process gives faithful reproductions of the master, but can be limited when plating into deep narrow slots or holes. Electroplating builds up more material on exterior corners and narrow slots can be closed at the top before they have plated enough at the bottom. This can be partially overcome by reducing the current, but this increases the time to produce the shell.

Express Tool (Warwick, Rhode Island) is developing an electroforming process that it plans to commercialize. The company typically produces the patterns by machining graphite. This material is an excellent conductor and it machines many times faster than aluminum. Another benefit to using graphite is that it serves as a natural release due to its lubricant properties – making it easier to separate it from the nickel shell.

An advantage of electroforming is that it is very good at the reproduction of detail. Disadvantages are that the process is not particularly fast and it's not possible to do deep slots or holes.

12.Cast Aluminum and Zinc Kirksite Tooling

For higher production volumes and more aggressive polymers, it is critical that the tool material has a high degree of mechanical hardness. Using molten metal casting techniques, it is possible to cast around an accurate pattern with either aluminum- or zinc-based alloys with a two-week leadtime.

Given the casting temperature of both aluminum and zinc it is important to replicate the initial pattern into a material capable of withstanding such heat. Using silicone tooling, as detailed earlier, a cavity is produced around the model. However, rather than a resin copy being made, the silicone cavity is then filled with ceramic. After drying, the ceramic facsimile is placed into a bolster and covered with the molten metal.

Cast aluminum and zinc kirksite tooling offer a simple and low-cost method of tooling. Disadvantages include a distortion of tools, accuracy problems due to shrinking, and geometry limitations (i.e., no fine features).

13.Investment Cast Tooling

Some companies have used investment casting with RP models to produce metal tooling. Most of the tools cast so far have been in aluminum, but there are some examples of tool steel molds. If a steel or hardened alloy cavity is required, either for mechanical strength and thermal cycling or due to high-volume production, investment cast tooling can offer an alternative to open cast tools, such as the kirksite process. By making a sacrificial RP model of the desired cavity, the lost wax process can be used to replicate the part in a metal.

The RP pattern is first invested in multiple layers of ceramic slurry, which are allowed to dry between coats. After the shell has dried, the ceramic shell and invested part are fired. The firing process sinters the ceramic shell and causes the invested model to be burned out. After firing, any ash residue is washed from the ceramic shell. The molten alloy of the tool material is then poured through a gating system into the void left by the RP pattern. After solidification and cooling, the ceramic shell is fractured and the newly formed metal cavity is removed and post-process machined.

Investment cast tools have been used for injection mold cavities and die casting tools. However, due to the unpredictable contraction of the casting process, it is difficult to maintain a high level of accuracy with this tooling process.

An advantage to the process is that you can get better detail than with cast aluminum or kirksite tooling. Distortion, limited accuracy and the need for finish machining are disadvantages.

14. 3D Keltool

The 3D Keltool process typically starts with a CAD design of the core and cavity mold inserts, followed by the creation of the core and cavity patterns with stereolithography or some other RP process. Once these core and cavity patterns have been finished to the desired surface, silicone rubber is cast against them to create molds into which a mixture of metal powder and binder is poured, packed and cured. The metal mixture consists of finely powdered A6 tool steel and even finer particles of tungsten carbide. At this point, the cast core and cavity inserts exist in a green state. These green inserts are fired in a hydrogen-reduction furnace to burn away the binder, sinter the metal particles and infiltrate copper into the inserts. This produces solid metal inserts that are approximately 70 percent steel and 30 percent copper with physical properties similar to that of P20 tool steel. The inserts are finish-machined, drilled for ejector pins and fitted into mold bases.

The tools from this process show very good definition and surface finish. Lead-time is typically shorter than conventionally produced tooling. The primary disadvantage is size limitation. The maximum size of a mold insert is 150 x 215 x 100 mm (5.9 x 8.5 x 4 inches). The length in the z-direction can extend to 145 mm (5.75 inches) when the x and/or y dimensions are shorter. Some toolmakers have press fit two or more inserts side-by-side – in a mold base – to create larger tools

Laminated Tooling

Laminated tooling is an alternative to building cavities directly on an RP machine. Using the similar principles to the Laminated Object Manufacturing (LOM) process,

layers of sheet metal are cut to replicate slices through a CAD model. Laser cutting or water jet technologies generally produce the profiles.

To produce a mold tool, the CAD model must take the form of the required cavity. By cutting all of the slices of the cavity in sheet metal, a stack of laminates can be made to replicate the original CAD model. Using either clamping or diffusion bonding, it is possible to create a pseudo-solid cavity in hardened tool steel without the need for complex post process cutter path planning. Due to the use of relatively thick laminates – typically 0.040 inch (1 mm) – the surface finish of the tools is generally poor; therefore, some form of finish machining is generally required.

Laminated tools have been used successfully for a variety of techniques including press tools, blow molding, injection molding and thermal forming. Research also is being performed into the use of laminate tools in pressure die-casting. Tool life is a function of the initial sheet material, which can be hardened after cutting and lamination. However, part complexity is bounded by layer thickness.

One significant advantage of laminated tooling is the ability to change the design of parts quickly by the replacement of laminates (if un-bonded). Conformal cooling channels also are easily incorporated within the tool design and laminated tooling is good for large tools as well. The need for finish machining to remove the stair steps is the main disadvantage of this process.

Powder Metallurgy based Technology

Powder metallurgy (PM) is a term covering a wide range of ways in which materials or components are made from metal powders. PM processes can avoid, or greatly reduce, the need to use metal removal processes, thereby drastically reducing yield losses in manufacture and often resulting in lower costs.

Powder metallurgy is also used to make unique materials impossible to get from melting or forming in other ways. A very important product of this type is tungsten carbide (WC). WC is used to cut and form other metals and is made from WC particles bonded with cobalt. It is very widely used in industry for tools of many types and globally ~50,000 tonnes/year (t/y) is made by PM. Other products include sintered filters, porous oil-impregnated bearings, electrical contacts and diamond tools.

Since the advent of industrial production–scale metal powder–based additive manufacturing (AM) in the 2010s, selective laser sintering and other metal AM processes are a new category of commercially important powder metallurgy applications.

Powder production techniques

Any fusible material can be atomized. Several techniques have been developed which permit large production rates of powdered particles, often with considerable control over the size ranges of the final grain population. Powders may be prepared by crushing, grinding, chemical reactions, or electrolytic deposition. The most commonly used powders are copper-base and iron-base materials.[10]

Powders of the elements titanium, vanadium, thorium, niobium, tantalum, calcium, and uranium have been produced by high-temperature reduction of the corresponding nitrides and carbides. Iron, nickel, uranium, and beryllium submicrometre powders are obtained by reducing metallic oxalates and formates. Exceedingly fine particles also have been prepared by directing a stream of molten metal through a high-temperature plasma jet or flame, atomizing the material. Various chemical and flame associated powdering processes are adopted in part to prevent serious degradation of particle surfaces by atmospheric oxygen.

In tonnage terms, the production of iron powders for PM structural part production dwarfs the production of all of the non-ferrous metal powders combined. Virtually all iron powders are produced by one of two processes: the sponge iron process or water atomization.

1.Sponge iron process

The longest established of these processes is the sponge iron process, the leading example of a family of processes involving solid state reduction of an oxide. In the process, selected magnetite (Fe_3O_4) ore is mixed with coke and lime and placed in a silicon carbide retort. The filled retort is then heated in a kiln, where the reduction process leaves an iron "cake" and a slag. In subsequent steps, the retort is emptied, the reduced iron sponge is separated from the slag and is crushed and annealed.

The resultant powder is highly irregular in particle shape, therefore ensuring good "green strength" so that die-pressed compacts can be readily handled prior to sintering, and each particle contains internal pores (hence the term "sponge") so that the good green strength is available at low compacted density levels.

Sponge iron provides the feedstock for all iron-based self-lubricating bearings, and still accounts for around 30% of iron powder usage in PM structural parts.

2.Atomization

Atomization is accomplished by forcing a molten metal stream through an orifice at moderate pressures. A gas is introduced into the metal stream just before it leaves the nozzle, serving to create turbulence as the entrained gas expands (due to heating) and exits into a large collection volume exterior to the orifice. The collection volume is filled with gas to promote further turbulence of the molten metal jet. Air and powder streams are segregated using gravity or cyclonic separation. Most atomized powders are annealed, which helps reduce the oxide and carbon content. The water atomized particles are smaller, cleaner, and nonporous and have a greater breadth of size, which allows better compacting. The particles produced through this method are normally of spherical or pear shape. Usually, they also carry a layer of oxide over them.

There are three types of atomization:

- Liquid atomization
- Gas atomization
- Centrifugal atomization

Simple atomization techniques are available in which liquid metal is forced through an orifice at a sufficiently high velocity to ensure turbulent flow. The usual performance index used is the Reynolds number R = fvd/n, where f = fluid density, v = velocity of the exit stream, d = diameter of the opening, and n = absolute viscosity. At low R the liquid jet oscillates, but at higher velocities the stream becomes turbulent and breaks into droplets. Pumping energy is applied to droplet formation with very low efficiency (on the order of 1%) and control over the size distribution of the metal particles produced is rather poor. Other techniques such as nozzle vibration, nozzle asymmetry, multiple impinging streams, or molten-metal injection into ambient gas are all available to increase atomization efficiency, produce finer grains, and to narrow the particle size distribution. Unfortunately, it is difficult to eject metals through orifices smaller than a few millimeters in diameter, which in practice limits the minimum size of powder grains to approximately 10 μm. Atomization also produces a wide spectrum of particle sizes, necessitating downstream classification by screening and remelting a significant fraction of the grain boundary.

3.Centrifugal disintegration

Centrifugal disintegration of molten particles offers one way around these problems. Extensive experience is available with iron, steel, and aluminium. Metal to be powdered is formed into a rod which is introduced into a chamber through a rapidly rotating spindle. Opposite the spindle tip is an electrode from which an arc is established which heats the metal rod. As the tip material fuses, the rapid rod rotation throws off tiny melt droplets which solidify before hitting the chamber walls. A circulating gas sweeps particles from the chamber. Similar techniques could be employed in space or on the Moon. The chamber wall could be rotated to force new powders into remote collection vessels,[11] and the electrode could be replaced by a solar mirror focused at the end of the rod.

An alternative approach capable of producing a very narrow distribution of grain sizes but with low throughput consists of a rapidly spinning bowl heated to well above the melting point of the material to be powdered. Liquid metal, introduced onto the surface of the basin near the center at flow rates adjusted to permit a thin metal film to skim evenly up the walls and over the edge, breaks into droplets, each approximately the thickness of the film.[12]

Other techniques

Another powder-production technique involves a thin jet of liquid metal intersected by high-speed streams of atomized water which break the jet into drops and cool the powder before it reaches the bottom of the bin. In subsequent operations the powder is dried. This is called water atomization. The advantage of water atomization is that metal solidifies faster than by gas atomization since the heat capacity of water is some magnitudes higher than gases. Since the solidification rate is inversely proportional to the particle size, smaller particles can be made using water atomization. The smaller the particles, the more homogeneous the micro structure will be. Notice that particles will have a more irregular shape and the particle size distribution will be wider. In addition, some surface contamination can occur by oxidation skin formation. Powder can be reduced by some kind of pre-consolidation treatment, such as annealing used for the manufacture of ceramic tools.

1.Powder compaction

Rhodium metal: powder, pressed pellet (3×10^5 psi) remelted.

Powder compaction is the process of compacting metal powder in a die through the application of high pressures. Typically the tools are held in the vertical orientation with the punch tool forming the bottom of the cavity. The powder is then compacted into a shape and then ejected from the die cavity. In a number of these applications the parts may require very little additional work for their intended use; making for very cost efficient manufacturing.

The density of the compacted powder increases with the amount of pressure applied. Typical pressures range from 80 psi to 1000 psi (0.5 MPa to 7 MPa), pressures from 1000 psi to 1,000,000 psi have been obtained. Pressure of 10 t/in² to 50 t/in² (150 MPa to 700 MPa) are commonly used for metal powder compaction. To attain the same compression ratio across a component with more than one level or height, it is necessary to work with multiple lower punches. A cylindrical workpiece is made by single-level tooling. A more complex shape can be made by the common multiple-level tooling.

Production rates of 15 to 30 parts per minute are common.

There are four major classes of tool styles: single-action compaction, used for thin, flat components; opposed double-action with two punch motions, which accommodates thicker components; double-action with floating die; and double action withdrawal die. Double action classes give much better density distribution than single action. Tooling must be designed so that it will withstand the extreme pressure without deforming or bending. Tools must be made from materials that are polished and wear-resistant.

Better workpiece materials can be obtained by repressing and re-sintering.

Powder Compaction Press

2.Die pressing

The dominant technology for the forming of products from powder materials, in terms of both tonnage quantities and numbers of parts produced, is die pressing. There are mechanical, servo-electrical and hydraulic presses available in the market, whereby the biggest powder throughput is processed by hydraulic presses. This forming technology involves a production cycle comprising:

1. Filling a die cavity with a known volume of the powder feedstock, delivered from a fill shoe.
2. Compaction of the powder within the die with punches to form the compact. Generally, compaction pressure is applied through punches from both ends of the toolset in order to reduce the level of density gradient within the compact.
3. Ejection of the compact from the die, using the lower punch(es) withdrawal from the die.
4. Removal of the compact from the upper face of the die using the fill shoe in the fill stage of the next cycle, or an automation system or robot.

This cycle offers a readily automated and high production rate process.

Design considerations

Probably the most basic consideration is being able to remove the part from the die after it is pressed, along with avoiding sharp corners in the design. Keeping the maximum surface area below 20 square inches (0.013 m^2) and the height-to-diameter ratio below 7-to-1 is recommended. Along with having walls thicker than 0.08 inches (2.0 mm) and keeping the adjacent wall thickness ratios below 2.5-to-1.

One of the major advantages of this process is its ability to produce complex geometries. Parts with undercuts and threads require a secondary machining operation. Typical part sizes range from 0.1 square inches (0.65 cm^2) to 20 square inches (130 cm^2). in area and from 0.1 to 4 inches (0.25 to 10.16 cm) in length. However, it is possible to produce parts that are less than 0.1 square inches (0.65 cm^2) and larger than 25 square inches (160 cm^2). in area and from a fraction of an inch (2.54 cm) to approximately 8 inches (20 cm) in length.

3.Isostatic pressing

In some pressing operations, such as hot isostatic pressing (HIP) compact formation and sintering occur simultaneously. This procedure, together with explosion-driven compressive techniques is used extensively in the production of high-temperature and high-strength parts such as turbine disks for jet engines. In most applications of powder metallurgy[14] the compact is hot-pressed, heated to a temperature above which the materials cannot remain work-hardened. Hot pressing lowers the pressures required to reduce porosity and speeds welding and grain deformation processes. It also permits better dimensional control of the product, lessens sensitivity to physical characteristics of starting materials, and allows powder to be compressed to higher densities than with cold pressing, resulting in higher strength. Negative aspects of hot pressing include shorter die life, slower throughput because of powder heating, and the frequent necessity for protective atmospheres during forming and cooling stages.

Full Mold Casting

Full-mold casting is an evaporative-pattern casting process which is a combination of sand casting and lost-foam casting. It uses an expanded polystyrene foam pattern which is then surrounded by sand, much like sand casting. The metal is then poured directly into the mold, which vaporizes the foam upon contact.

First, a pattern is usually made from polystyrene foam, which can be done many different ways. For small volume runs the pattern can be hand cut or machined from a solid block of foam; if the geometry is simple enough it can even be cut using a hot-wire foam cutter.
If the volume is large, then the pattern can be mass-produced by a process similar to injection molding. Pre-expanded beads of polystyrene are injected into a preheated aluminum mold at low pressure. Steam is then applied to the polystyrene which causes it to expand more to fill the die. The final pattern is approximately 97.5% air and 2.5% polystyrene.

The finished patterns can be hot glued to pre-made pouring basins, runners, and risers to form the final pattern.The pattern is then coated with a refractory material. The coated pattern is placed in a flask and packed carefully with green sand or a chemically bonded sand.

Finally, the molten metal is poured into the mold, which vaporizes the foam allowing the metal to fill the entire mold. The vapor is simultaneously extracted from the flask through the sand.
The casting is allowed to cool and then dumped out of the flask ready to use. The sand does not need to be reprocessed so it can be directly reused.
The minimum wall thickness for a full-mold casting is 2.5 mm (0.10 in). Typical dimensional tolerances are 0.3% and typical surface finishes are from 2.5 to 25 µm (100 to 1000 µin) RMS. The size range is from 400 g (0.88 lb) to several tonnes (tons).
Full-mold casting is often used to produce cylinder heads, engine blocks, pump housings, automotive brake components, and manifolds. Commonly employed materials include aluminium, iron, steel, nickel alloys, and copper alloys.

Advantages and disadvantages

This casting process is advantageous for very complex castings, that would regularly require cores. It is also dimensionally accurate, requires no draft, and has no parting lines so no flash is formed. As compared to investment casting, it is cheaper because it is a simpler process and the foam is cheaper than the wax. Risers are not usually required due to the nature of

the process; because the molten metal vaporizes the foam the first metal into the mold cools more quickly than the rest, which results in natural directional solidification.
The two main disadvantages are that pattern costs can be high for low volume applications and the patterns are easily damaged or distorted due to their low strength. If a die is used to create the patterns there is a large initial cost.

Quick cast

Investment casting has, without a doubt, earned its place in manufacturing. The lost-wax process has proven to be a cost effective way to produce prototypes, short runs or full production metal components. Parts can be reduced in weight, tolerances of ± .005″ per inch held, and expenses and time involving machining and finishing reduced or eliminated. The bottom line is, many parts are perfect candidates for investment casting.
QuickCast is an SLA build style and was created to meet the needs of the Investment Casting industry. QuickCast patterns were the first direct pattern (patterns created via a 3D printing
QuickCast patterns for investment casting have had the most profound effect on this industry. QuickCast replaces the time consuming process of creating tooling to produce wax patterns, allowing the review of metal designs in days instead of months.
QuickCast patterns are a hollow SLA build style with hexagonal support structures.
The QuickCast build style consists of a hollow stereolithography pattern with an internal hexagonal support structure that adds strength to the pattern, allows for easy drainage, and facilitates collapse of the pattern during thermal expansion to help avoid cracking the shell. QuickCast patterns provide several advantages compared to other direct patterns including low moisture absorption, high finish, dimensional stability and capabilities of producing large assemblies.

UNIT-9
EMERGING TRENDS IN RT

REVERSE ENGINEERING

In mechanical engineering, the term reverse engineering (often abbreviated to RE) is used to summarise the process of reconstructing an existing object. When designing an object from scratch, an engineer will draw up a design specification and produce drawings from which the item is constructed.

Conversely, with reverse engineering, the design engineer starts with the final product and works through the design process in the opposite direction to arrive at the product design specification. During the process, vital information about the design concept and manufacturing methods is discovered.

The process of reverse engineering begins by gaining dimensional information of the object via 3D scanning, whether it is a mechanical component, a consumer product or an ancient artefact.

Reverse engineering involves acquiring three-dimensional positional data in the point cloud. There are many ways of gathering valuable dimensional information about the product, but using an accurate 3D measuring system is paramount. The accuracy of the data captured will impact the quality and deviation of the Reverse Engineered model when compared to the original.

Physical Digital uses the globally-recognised GOM 3D structured light scanning systems, which offer highly-accurate, traceable and repeatable measurement. The surface data captured is then passed to our in-house design team to establish the original design intent of the object.

Reverse engineering enables the duplication of an existing part by capturing the component's physical dimensions, features, and material properties. There are a wide range of reasons for reverse engineering an object, including:

Legacy Components – For many components that were designed and manufactured years ago, there are no existing 2D drawings or 3D CAD data from which to reproduce the object. Here, reverse engineering is a vital means to gain the information to recreate the product.

Original Equipment Manufacturer (OEM) issues – If the OEM is no longer trading or has lost design measurements, then Reverse Engineering will supply the vital product information to continue manufacturing of that object.

Design Development, Part Testing & Analysis – Through reverse engineering, a 3D product can be quickly captured in digital form and remodelled or analysed in order to achieve improved design iterations.

Competitor Analysis – Any organisation can analyse competitor products through reverse engineering.

Bespoke and Ancient objects – Where there is no information about the dimensions of an object except for the physical item itself, the quickest and most reliable way to reproduce it will be by reverse engineering. Where a product is organic in shape (not a standard geometry such as cuboid or cylindrical), designing in CAD may be challenging as it can be difficult to ensure that the CAD model will be acceptably close to the sculpted model. Reverse engineering avoids this problem as the physical model is the source of the information for the CAD model.

Modern manufacturing – methods such as Additive Manufacturing rely on reverse engineering.
Digital Archiving – Museum pieces and historic artefacts can be captured through 3D scanning, then reverse engineered and the resulting CAD data can be held in case of any future damage to the object or any need to reproduce parts of the item.

REVERSE ENGINEERING AND PRODUCT PROTOTYPING

Reverse engineering is commonly applied to the general process of recreating existing 3D geometry in the computer. This 3D geometry could be the shape of a real, manufactured object, like a car, or it could be some type of organic shape, like a plant or a human body.
Although many manufactured objects are now defined digitally using some type of 3D modeling software, in many instances, the part may not be able to obtain the existing geometry digitally. For example, the digital geometry might be needed for part repair or during product development iterations. For example, engineers may want to put the shape of an old VW Beetle into the computer so that they could construct an oversized sculpture of the car. It could also be an engineer who wants to capture the shape of an airplane to put into a flight simulator program. For nonmanufactured objects, such as rocks, trees, and human beings, there are no existing computer models and one has no choice but to re-create the 3D shape on the computer. In general, CAD models are often unavailable or unusable for parts which must be duplicated or modified when:

1. CAD was not used in the original design,
2. there is inadequate documentation on the original design,
3. the original CAD model is not sufficient to support modification or manufacturing using modern methods,
4. the original supplier is unable or unwilling to provide additional parts, or
5. there have been shop floor changes to the original design.

The reverse-engineering machines require very high precision, and thus there are some standard procedures to ensure that the machine is well qualified before it is used.For example, the CMM is an accurate measuring device used to verify dimensions to ensure part quality. A CMM can be used to measure features in 2D and 3D, although 2D features cannot be measured directly. For example, a line is a 2D feature, and can be defined by the intersection of a plane to the reference plane. While a plane is a 3D feature, a line can be indirectly defined by defining two planes using a CMM. Most parts are made up of simple geometric elements such as planes, edges, cylinders, spheres, and cones, created by machining or forming. Distance, symmetry, intersection, angle, and projection cannot
be measured directly, but must be constructed mathematically from measured features.

Projection is the reproduction of a workpiece feature on another feature, for example, projecting a circle or line on a plane, or a point onto a line. Intersection is where two existing geometric elements meet and cross each other. For example, points are created by the intersection of two lines, or of a line and a plane; and lines are created by the intersection of two planes.
The sequence for programming a CMM with a probe includes the following steps:

1. Home the CMM, and establish a global coordinate system.

2. Qualify the tip, and compensate for tip diameter. Probe qualification is critical for machine accuracy, especially when the machine is started each day or when a new probe is installed. To qualify the tip, one needs to 172 Rapid Prototyping and Engineering Applications: A Toolbox for Prototype Development

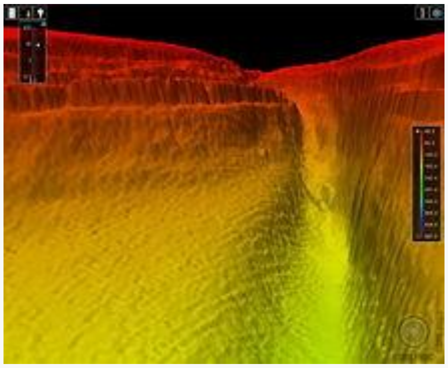
A. Measure a reference sphere
B. Enter the reference sphere diameter, actual probe diameter, and probe positions into the computer
C. The computer calculates the effective probe diameter and location of the center of the probe in the measuring volume
3. Align the part, and establish a local coordinate system on the part. To align a part with its CAD model, one needs to align
A. The reference plane
B. The major axis
C. The part zero
4. Measure the part.

Traditional CMMs typically have better accuracy, but can be limited in the size and complexity of the object to be scanned. Portable CMMs are generally less accurate, but they are portable, with less limitation on the size of an object. Measurement systems using noncontact technologies, such as various laser scanning probes or laser tracking systems, can scan
very large and complex surfaces accurately, but can be very expensive depending on the type of system. Sensing can be classified into passive sensing and active sensing. Passive sensing is when sensing energy is only received and no energy is emitted for the purpose of sensing, for example, stereo vision techniques. Active sensing is when properly formatted light or any other form of
energy is emitted rather than received once it has interacted with the object to digitize, for example, CT (computerized omography) and MRI (magnetic resonance imaging).

Geometric Data Acquistion

The acquisition and maintenance of the geometric data base is an important cost factor for a geographical information system (GIS). The goal of the acquisition process is to encode and store the geometric features as accurately as necessary, and as economically as possible. Operator-guided digitizing and raster-to-vector conversion are the two techniques mainly applied for the capture of geometric data. Both techniques have specific advantages for certain classes of applications with respect to accuracy and economics. Although it is called an "old" technique, operator-guided digitizing can still be the most economical solution for many digitizing tasks. The economics can be improved by technical enhancements, for example the use of the acoustical channel, or by implementing the appropriate strategy for object capture. Additional tools beyond the basic storage and retrieval functions facilitate the management of geometric data.
3D reconstruction is the process of capturing the shape and appearance of real objects. This process can be accomplished either by active or passive methods.[1] If the model is allowed to change its shape in time, this is referred to as non-rigid or spatio-temporal reconstruction.[2]

Active methods



3D echo sounding map of an underwater canyon

Active methods, i.e. range data methods, given the depth map, reconstruct the 3D profile by numerical approximation approach and build the object in scenario based on model. These methods actively interfere with the reconstructed object, either mechanically or radiometrically using rangefinders, in order to acquire the depth map, e.g. structured light, laser range finder and other active sensing techniques. A simple example of a mechanical method would use a depth gauge to measure a distance to a rotating object put on a turntable. More applicable radiometric methods emit radiance towards the object and then measure its reflected part. Examples range from moving light sources, colored visible light, time-of-flight lasers [6] to microwaves or 3D ultrasound. See 3D scanning for more details.

Passive methods

Passive methods of 3D reconstruction do not interfere with the reconstructed object; they only use a sensor to measure the radiance reflected or emitted by the object's surface to infer its 3D structure through image understanding. Typically, the sensor is an image sensor in a camera sensitive to visible light and the input to the method is a set of digital images (one, two or more) or video. In this case we talk about image-based reconstruction and the output is a 3D model. By comparison to active methods, passive methods can be applied to a wider range of situations.

Monocular cues methods

Monocular cues methods refer to using one or more images from one viewpoint (camera) to proceed to 3D construction. It makes use of 2D characteristics(e.g. Silhouettes, shading and texture) to measure 3D shape, and that's why it is also named Shape-From-X, where X can be silhouettes, shading, texture etc. 3D reconstruction through monocular cues is simple and quick, and only one appropriate digital image is needed thus only one camera is adequate. Technically, it avoids stereo correspondence, which is fairly complex.

Shape-from-shading Due to the analysis of the shade information in the image, by using Lambertian reflectance, the depth of normal information of the object surface is restored to reconstruct.

Photometric Stereo This approach is more sophisticated than the shape-of-shading method. Images taken in different lighting conditions are used to solve the depth information. It is worth mentioning that more than one image is required by this approach.[12]

Shape-from-texture Suppose such an object with smooth surface covered by replicated texture units, and its projection from 3D to 2D causes distortion and perspective. Distortion and perspective measured in 2D images provide the hint for inversely solving depth of normal information of the object surface.

Rapid Tooling: Its Processes, Advantages, and Applications

If you want to market your product faster, you will need rapid prototyping to make the parts readily available for testing. There are many innovations in the manufacturing industry in recent years. And among them are the various rapid prototyping techniques that can help the design team during the product development phase. It's called rapid prototyping.

Thanks to rapid tooling, parts are manufactured quickly to test and validate them before going into production tooling. There are different names for rapid tooling. Some people call it **prototypes tooling**, **soft tooling**, or **prototype mold**. For now, let us stick with rapid tooling.

This article will dig deeper into this buzzword and look at its advantages and applications. Before we move into that, let us first get to know what rapid tooling is.

Rapid Tooling Products

The Beginning of Rapid Tooling

Simply put, rapid tooling is a process of creating a prototype in a short time. It all began in the 1990s where engineers using plastic injection molding tried to find ways to create molds in days or even hours instead of the number of months it took them to produce a machine mold.

Parts made through rapid tooling is a perfect solution to test and evaluate a prototype and make a few hundred parts before actually going into full production mode. Rapid tooling techniques build inserts like the core, side actions, and cavity of the parts. It all depends on the rapid tooling employed; it can produce parts through multiple cycles out of the same mold.

There are many rapid tooling techniques to choose from, and each type can have various benefits. You have many factors to consider for getting the most of these benefits because it varies depending on the size, consistency, technology, accuracy, and the materials you will use.

You have to keep the following limitations in mind, too, if you are considering rapid tooling to make your prototype.

1. The mold should be strong

The mold has to be durable so that it can manage the injection molding method. The molding machines clamped heated materials into the mold at pounds per inch, so the molds should withstand the injections.

2. The mold should be smooth

Aside from being strong, it should also be smooth to inject the plastic cleanly. This characteristic is critical because it is needed for each ejection. In rapid tooling, some processes add materials layer by layer, so it's not smooth. In this case, the prototype requires additional finishing to be viable for prototyping.

One thing about rapid tooling is it uses the exact material of the final product. It's good because you can have a more precise idea of how the parts will be in actual utilization. Thus, you can explore and confirm if you have the right material.

Benefits of Rapid Tooling
Here are the other benefits of rapid tooling

It provides an opportunity for innovation
Because rapid tooling eliminates the use of conventional tooling, it initiates up a new range of opportunities for improvements. Traditional prototyping takes a long time because it needs making the prototype tooling and its components to exact the tolerances. In rapid prototyping, the designers can conceive complex geometries that will be impossible to develop in conventional prototyping too.

Time-saving
Rapid tooling is time-saving because it eliminates the need to produce molds, patterns, and special tools that you used in conventional tooling. Because of this, rapid tooling shortened the time between the initial idea and evaluation.
The resulting prototypes are accurate and readily accessible for testing the forms, features, usability, and performance. Its designers can also modify the product based on the feedback. A fast turnaround can help the company to obtain a competitive edge to bring new products into the market.

Cost Savings
Another benefit of rapid tooling is the cost savings. The part produced in rapid tooling is synonymous with full-scale production. You can use these parts for impact and stress testing. With the results from testing, you can determine the changes needed before going into an expensive tooling process.

Applications of Rapid Tooling
There are many applications for rapid tooling, and these applications will continue to grow because of the development of new procedures. Here are some of them:
The making of molds – both metallic and non-metallic molds can be made through rapid tooling.
The making of casting shapes and cores – SLS application is the latest technology invented in sand casting shapes and cores.
The electrodes for EDM, making of marking stamps, production of hybrid patterns for casting, and producing splintering tools are some of the applications of rapid tooling.
There are many reasons why you should consider rapid tooling. It is a low cost, quick and effective way that will allow you to market parts faster. The cost advantage is the most useful because it will enable market testing, which is suitable for low volume production.

Development of Medical Devices and Instrumentations

Other important applications of the prototyping technology are in the development of medical devices and instrumentations. Medical instruments that have been upgraded using the 3D technology include surgical fasteners, scalpels, retractors, display systems, among many others.

Besides the designing of the medical devices, the prototyping technology is also used in the manufacturing of these devices. Devices that need to be specifically individualized for a particular patient are the candidates of the additive technologies.
Most hearing aid devices are designed using the stereolithography or the selective laser sintering. Other areas that are adapting the rapid prototyping technology is the replacement of teeth.
Some drug dosage forms are also designed by the use of these technology. Especially the dosage forms that are difficult to design using any other method.
Tablets having a sustained drug release are also being manufacture using the rapid prototyping technology. The new technology has improved the safety of drugs to patients by minimizing the adverse drug reactions that may arise.

Application in the Manufacture of Prostheses and Implants

Rapid prototyping plays a crucial role when it comes to implantations and use of prostheses. Through the technology, prostheses that have been specifically designed for a particular patient are now available. Patients whose requirement is outside the standard size or those who require special treatments can now get some customized prostheses that fits them at an affordable cost.
Rapid prototyping and computed tomography technologies utilize techniques, such as X-rays and NMRI, and enable the transfer of data generated to be used as the input data for the rapid prototyping process. A lot of development have been done to enhance the accuracy, interpretation, and the translation of the CT scan results. The accuracy of the models generated from the rapid prototyping systems have also been improved over time.
Various types of rapid prototyping technology have been applied in the various medical uses with some of them being selected as the standard method. An example of standard method used for medical purposes is the CT scan used in the hip replacement surgical procedure.
Data from the CT scan is combined with engineering data to join to the bone. The data is then turned into a plastic model to be applied as an implant for the patient.
Other medical applications of the prototyping technologies is in the replacement of the external missing organs. In such instances, the remaining organ is scanned into a three-dimensional image, and the mirror-image of the data acquired is used to build data for the missing organ.

Planning for Surgical Procedures and Other Scientific Applications

Models of complex organs in the body are being developed using the rapid prototyping techniques. The models are used by surgeons to get the real impression of the structures before a surgical intervention is performed.
Complex procedures, especially those ones involving the craniofacial and the maxillofacial surgeries utilize the scientific application. The models are always placed in the surgical rooms where the procedure is being done by the surgeon.
The most commonly used technology for this application is the stereolithography. The model has some of the most reliable features, such as the transparency and developments in the color resins, enable a clear differentiation of tumors and any other foreign growth in the bodies.
Rapid prototyping technology is also used in the manufacture of biologically active implants and also in tissue engineering. The application involves the use of selective laser sintering of ceramics.

UNIT-10
PROCESSING POLYHEDRAL DATA

Polyhedral Compilation

Polyhedral compilation encompasses the compilation techniques that rely on the representation of programs, especially those involving nested loops and arrays, thanks to parametric polyhedra 952 or Presburger relations 31, and that exploit combinatorial and geometrical optimizations on these objects to analyze and optimize the programs. Initially proposed in the context of compilers-parallelizers, it is now used for a wide range of applications, including automatic parallelization, data locality optimizations, memory management optimizations, program verification, communication optimizations, SIMDization, code generation for hardware accelerators, high-level synthesis, etc. There has been experience in using such techniques in static compilers, just-in-time compilers, as well as DSL compilers. The polyhedral research community has a strong academic background, but more and more industry users start to adapt such technologies as well.

The interest of using polyhedral representations is that they can be manipulated or optimized with algorithms whose complexity depends on their structure and not on the number of elements they represent. Furthermore, generic and compact solutions can be designed that depend on program parameters (e.g., loop bounds, tile sizes, array bounds). In a word, polyhedral techniques are the symbolic counterpart, for structured loops (but without unrolling them), of compilation techniques (such as scheduling, lifetime analysis, register allocation) designed for acyclic control-flow graphs or unstructured loops. Also, compared to optimizations that handle loops or arrays as a whole, polyhedral techniques can work at the granularity of their elements, i.e., at the granularity of a loop iteration and instance of a statement (operation), and at the granularity of an array element

Boundary Representation (B-REP)

boundary representation—often abbreviated as B-rep or BREP—is a method for representing shapes using the limits. A solid is represented as a collection of connected surface elements, which define the boundary between interior and exterior points.

A boundary representation of a model comprises topological components (faces, edges and vertices) and the connections between them, along with geometric definitions for those components (surfaces, curves and points, respectively). A face is a bounded portion of a surface; an edge is a bounded piece of a curve and a vertex lies at a point. Other elements are the *shell* (a set of connected faces), the *loop* (a circuit of edges bounding a face) and *loop-edge links* (also known as *winged edge links* or *half-edges*) which are used to create the edge circuits.

Compared to the constructive solid geometry (CSG) representation, which uses only primitive objects and Boolean operations to combine them, boundary representation is more flexible and has a much richer operation set. In addition to the Boolean operations, B-rep has extrusion (or sweeping), chamfer, blending, drafting, shelling, tweaking and other operations which make use of these.

The basic method for BREP was developed independently in the early 1970s by both Ian C. Braid in Cambridge (for CAD) and Bruce G. Baumgart at Stanford (for computer vision). Braid continued his work with the research solid modeller BUILD which was the forerunner of many research and commercial solid modelling systems. Braid worked on the commercial systems ROMULUS, the forerunner of Parasolid, and on ACIS. Parasolid and ACIS are the basis for many of today's commercial CAD systems.

Following Braid's work for solids, a Swedish team led by Professor Torsten Kjellberg, developed the philosophy and methods for working with hybrid models, wire-frames, sheet objects and volumetric models during the early 1980s. In Finland, Martti Mäntylä produced a solid modelling system called GWB. In the USA Eastman and Weiler were also working on Boundary Representation and in Japan Professor Fumihiko Kimura and his team at Tokyo University also produced their own B-rep modelling system.

Initially CSG was used by several commercial systems because it was easier to implement. The advent of reliable commercial B-rep kernel systems like Parasolid and ACIS, mentioned above, as well as OpenCASCADE and C3D that were later developed, has led to widespread adoption of B-rep for CAD.

Boundary representation is essentially a local representation connecting faces, edges and vertices. An extension of this was to group sub-elements of the shape into logical units called *geometric features*, or simply *features*. Pioneering work was done by Kyprianou in Cambridge also using the BUILD system and continued and extended by Jared and others. Features are the basis of many other developments, allowing high-level "geometric reasoning" about shape for comparison, process-planning, manufacturing, etc.

Boundary representation has also been extended to allow special, non-solid model types called non-manifold models. As described by Braid, normal solids found in nature have the property that, at every point on the boundary, a small enough sphere around the point is divided into two pieces, one inside and one outside the object.] Non-manifold models break this rule. An important sub-class of non-manifold models are sheet objects which are used to represent thin-plate objects and integrate surface modelling into a solid modelling environment.

STL Format

In a nutshell, an STL file stores information about 3D models. This format describes only the surface geometry of a three-dimensional object without any representation of color, texture or other common model attributes.

These files are usually generated by a computer-aided design (CAD) program, as an end product of the 3D modeling process. ".STL" is the file extension of the STL file format.The STL file format is the most commonly used file format for 3D printing. When used in conjunction with a 3D slicer, it allows a computer to communicate with 3D printer hardware.

Since its humble beginnings, the STL file format has been adopted and supported by many other CAD software packages, and today is widely used for rapid prototyping, 3D printing, and computer-aided manufacturing. Hobbyists and professionals use it alike.The true meaning of the file extension .STL has been lost to the mists of time.

It's widely believed to be an abbreviation of the word **ST**ereo**L**ithography, though sometimes it is also referred to as "Standard Triangle Language" or "Standard Tessellation Language".The main purpose of the STL file format is to encode the surface geometry of a 3D object. It encodes this information using a simple concept called "tessellation".

Tessellation

Tessellation is the process of tiling a surface with one or more geometric shapes such that there are no overlaps or gaps. If you have ever seen a tiled floor or wall, that is a good real life example of tessellation.Tessellation can involve simple geometric shapes or very complicated (and imaginative) shapes.

STL File information

The STL file format provides two different ways of storing information about the triangular facets that tile the object surface. These are called the *ASCII encoding* and the *binary encoding*. In both formats, the following information of each triangle is stored:

1. The coordinates of the vertices.
2. The components of the unit normal vector to the triangle. The normal vector should point outwards with respect to the 3D model.

STL file 3D printed

For 3D printing, the STL file has to be opened in a dedicated slicer. What's a slicer? It's a piece of 3D printing software that converts digital 3D models into printing instructions for your 3D printer to create an object.The slicer chops up your STL file into hundreds (sometimes thousands) of flat horizontal layers based on the settings you choose and calculates how much material your printer will need to extrude and how long it will take to do it.

All of this information is then bundled up into a GCode file, the native language of your 3D printer. Slicer settings do have an impact the quality of your print so it's important to have the right software and settings to get you the best quality print possible.

Once the GCode has been uploaded to your 3D printer, the next stage is for those separate two-dimensional layers to be reassembled as a three-dimensional object on your print-bed. This is done by depositing a succession of thin layers of plastics, metals, or composite materials, and building up the model one layer at a time.

The STL file format is not the only format used in 3D printing. There are over 30 file formats for 3D printing. Most important is the OBJ file format, which can store color and texture profiles. Another option the is Polygon file format (PLY), which was originally used for storing 3D scanned objects.

More recently, there have been efforts to launch a new file type by The 3MF Consortium, which is proposing a new 3D printing file format called 3MF. They claim it will streamline and improve the 3D printing process.

To implement it, Microsoft has partnered up companies like Autodesk, HP, and Shapeways to make their vision a reality. More details on the 3MF Consortium can be read on their website, together with preliminary documentation about the 3MF file type on their GitHub page. It's far too early to say whether this will become widely adopted, however.

Advantages and disadvantages of STL file format

Since there are many 3D printing file formats, the obvious question is : which one should you use for your prints? The answer, as it turns out, depends a lot on your use case.

When *not* to use an STL file-As we saw earlier, the STL file format cannot store additional information such as color, material etc. of the facets or triangles. It only stores information about the vertices and the normal vector. This means that if you want to use multiple colors or multiple materials for your prints, then the STL file format is not the right choice. The OBJ format is a popular format enjoying good support which has a way to specify color, material etc. Therefore, this is the right choice for this task.

When to use an STL file-On the other hand, if you want to print with a single color or material, which is most often the case, then STL is better than OBJ since it is simpler, leading to smaller file sizes and faster processing.

Other advantages of the STL file format

Universal: Another big advantage of the STL file format is that it is universal and supported by nearly all 3D printers. This cannot be said for the OBJ format, even though it enjoys reasonable adoption and support as well. The VRML, AMF and 3MF formats are not widely supported at this point of time.

Mature ecosystem: Most 3D printable models you can find on the internet are in the STL file format. The existence of this ecosystem, combined with STL-based software investments made by 3D printer manufacturers, has given rise to a large user-base that's heavily invested in the format. This means there's plenty of third party software dealing with STL files, which is not the case with the other file formats. **Some disadvantages of the STL file format**

There are some glaring disadvantages to using STL as well. As the fidelity of printing processes embraces micron-scale resolution, the number of triangles required to describe smooth curved surfaces can result in massive file sizes. It's also impossible to include metadata (such as authorship and copyright information) in an STL file.

UNIT-11
INTRODUCTION TO SOFTWARE FOR RP

Software Prototype

Software prototyping is the activity of creating prototypes of software applications, i.e., incomplete versions of the software program being developed. It is an activity that can occur in software development and is comparable to prototyping as known from other fields, such as mechanical engineering or manufacturing.

A prototype typically simulates only a few aspects of, and may be completely different from, the final product.

Prototyping has several benefits: the software designer and implementer can get valuable feedback from the users early in the project. The client and the contractor can compare if the software made matches the software specification, according to which the software program is built. It also allows the software engineer some insight into the accuracy of initial project estimates and whether the deadlines and milestones proposed can be successfully met. The degree of completeness and the techniques used in prototyping have been in development and debate since its proposal in the early 1970s

The purpose of a prototype is to allow users of the software to evaluate developers' proposals for the design of the eventual product by actually trying them out, rather than having to interpret and evaluate the design based on descriptions. Software prototyping provides an understanding of the software's functions and potential threats or issues. Prototyping can also be used by end users to describe and prove requirements that have not been considered, and that can be a key factor in the commercial relationship between developers and their clients. Interaction design in particular makes heavy use of prototyping with that goal.

This process is in contrast with the 1960s and 1970s monolithic development cycle of building the entire program first and then working out any inconsistencies between design and implementation, which led to higher software costs and poor estimates of time and cost.[*citation needed*] The monolithic approach has been dubbed the "Slaying the (software) Dragon" technique, since it assumes that the software designer and developer is a single hero who has to slay the entire dragon alone. Prototyping can also avoid the great expense and difficulty of having to change a finished software product.

The practice of prototyping is one of the points Frederick P. Brooks makes in his 1975 book *The Mythical Man-Month* and his 10-year anniversary article "No Silver Bullet".

An early example of large-scale software prototyping was the implementation of NYU's Ada/ED translator for the Ada programming language.[3] It was implemented in SETL with the intent of producing an executable semantic model for the Ada language, emphasizing clarity of design and user interface over speed and efficiency. The NYU Ada/ED system was the first validated Ada implementation, certified on April 11, 1983.[4]

The process of prototyping involves the following steps]

1. Identify basic requirements
   Determine basic requirements including the input and output information desired. Details, such as security, can typically be ignored.
2. Develop initial prototype

The initial prototype is developed that includes only user interfaces. (See Horizontal Prototype, below)

3. Review
   The customers, including end-users, examine the prototype and provide feedback on potential additions or changes.
4. Revise and enhance the prototype
   Using the feedback both the specifications and the prototype can be improved. Negotiation about what is within the scope of the contract/product may be necessary. If changes are introduced then a repeat of steps #3 and #4 may be needed.

SOLID VIEW

SolidView Software from Stratasys Direct Manufacturing lets anyone view, measure, mark-up, and communicate 3D and 2D designs and assemblies using a standard Windows PC. SolidView's intuitive user interface makes it ideal for rapid prototyping, reverse engineering, and general view and mark-up applications. Extensive cross-sectioning and measurement features make it easy to identify and document design changes. Automatic slide record and playback, along with a complete suite of mark-up tools enable full 3D communication of complex designs and assemblies. With SolidView's exclusive publishing capabilities you can even send a no-cost 2D/3D player along with your designs. SolidView adds instant value to your existing CAD data by allowing everyone involved in the product development process-engineering, manufacturing, purchasing, Quality Assurance, suppliers, marketing and sales and even customers-to share the design data on their Windows PC.SolidView reads the following 3D and 2D formats: SLDPRT, SLDASM, TL, VRML, OBJ, DXF, CGM, HPGL, HPGL2, TIFF, GIF, BMP,Options for IGES and VDA import, as well as network licensing are also available.

SOFTWARE MAGICS

Magics rapid prototyping software enables you to import a wide variety of CAD formats and to export STL files ready for rapid prototyping, tooling and manufacturing. Its applications include repairing and optimizing 3D models; analyzing parts; making process-related design changes on your STL files; designing fixtures; documenting your projects; production planning and much more.