Eighth Semester B.E Degree Examination, June/July 2018

Solutions Key

Subject Code: 10ME837
Subject: Rapid Prototyping
Course Instructor: Prof.H.Manikandan

Course: B.E/Mechanical
Semester: VIII
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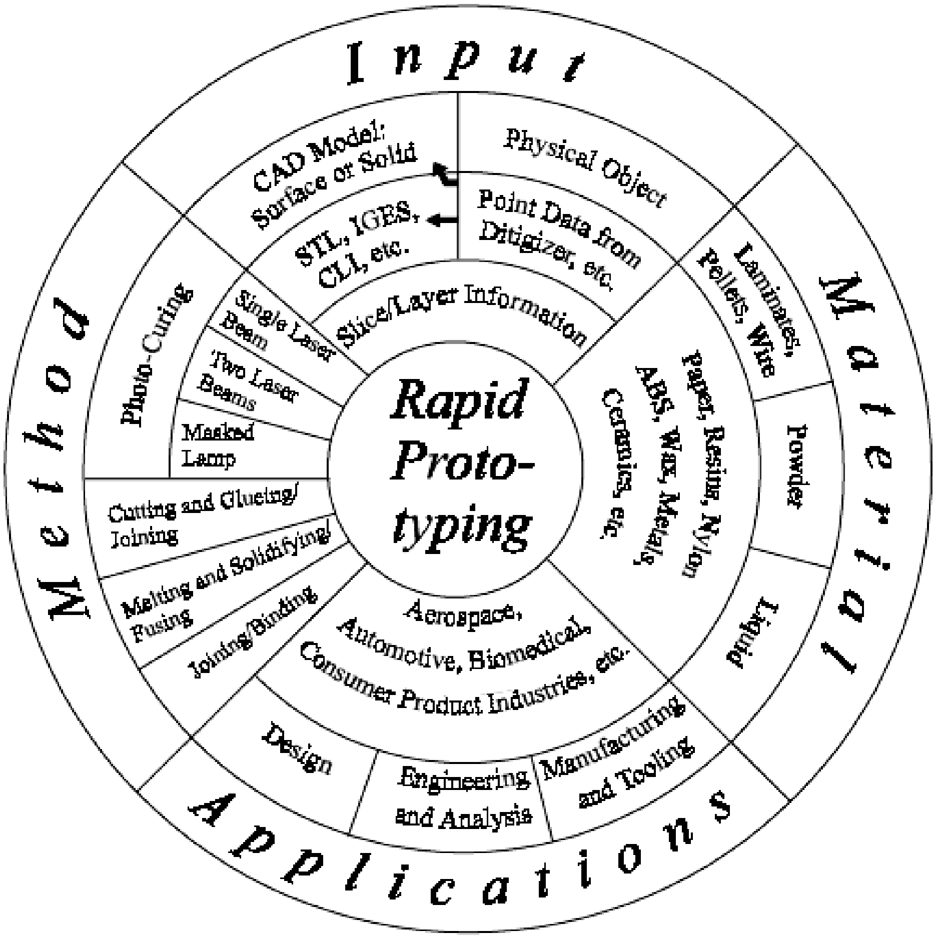
PART A

1.a) RP Wheel



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

1. INPUT

Input refers to the electronic information required to describe the physical object with 3D data. There are two possible starting points a computer model or a physical model. The computer model created by a CAD system can be either a surface model or a solid model. On the other hand, 3D data from the physical model is not at all straightforward. It requires data acquisition through a method known as reverse engineering. In reverse engineering, a wide range of equipment can be used, such as CMM (coordinate measuring machine) or a laser digitizer, to capture data points of the physical model and "reconstruct" it in a CAD system.

2. Method

While they are currently more than 20 vendors for RP systems, the method employed by each vendor can be generally classified into the following categories: photo-curing, cutting and glueing/joining, melting and solidifying/fusing and joining/binding. Photo-curing can be further divided into categories of single laser beam, double laser beams and masked lamp.

3. Material

The initial state of material can come in either solid, liquid or powder state. In solid state, it can come in various forms such as pellets, wire or laminates. The current range materials include paper, nylon, wax, resins, metals and ceramics.

4. Applications

Most of the RP parts are finished or touched up before they are used for their intended applications. Applications can be grouped into (1) Design (2) Engineering, Analysis, and Planning and (3) Tooling and Manufacturing. A wide range of industries can benefit from RP andthese include, but are not limited to, aerospace, automotive, biomedical, consumer, electrical and electronics products.

1.b) Rapid prototyping Process Chain

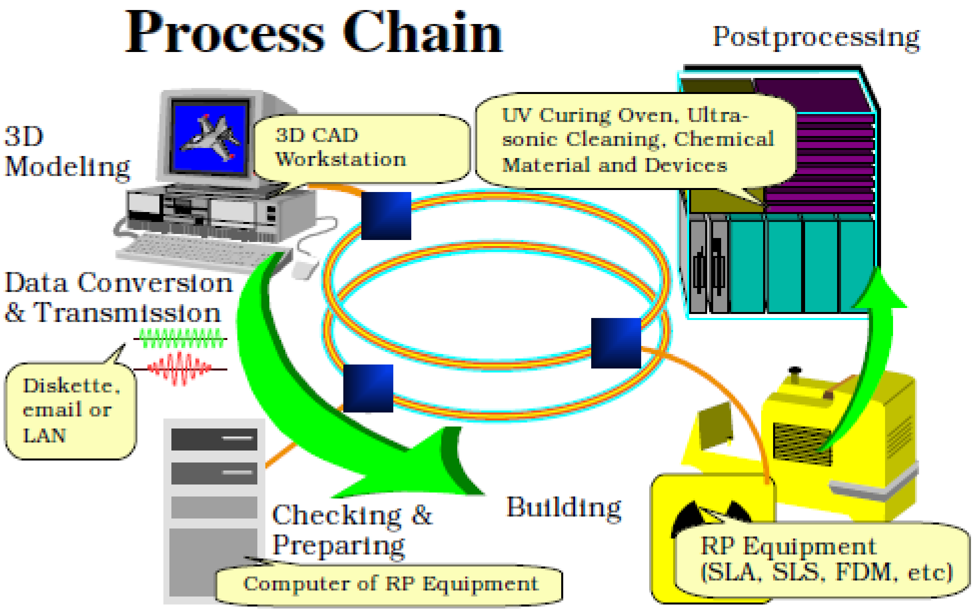
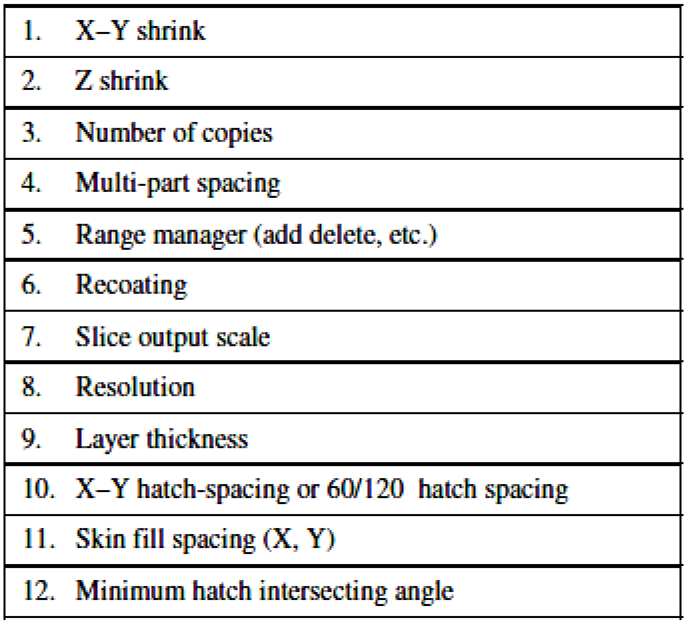


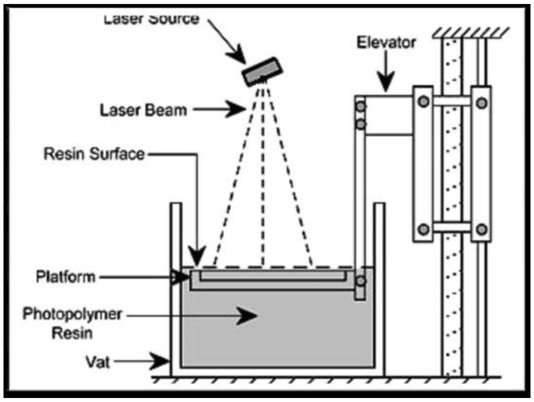
Figure 2.2: Process chain of Rapid Prototyping process

1.c) Stereolithography process

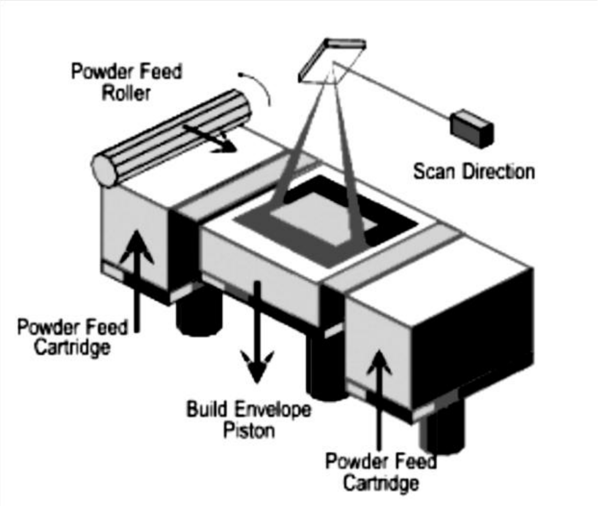
Once the STL files are verified to be error-free, the RP system's computer analyzes the STL files that define the model to be fabricated and slices the model into cross-sections. The cross-sections are systematically recreated through the solidification of liquids or binding of powders, or fusing of solids, to form a 3D model. In a SLA, for example, each output file is sliced into cross-sections, between 0.12 mm (minimum) to 0.50 mm (maximum) in thickness. Generally, the model is sliced into the thinnest layer (approximately 0.12 mm) as they have to be very accurate. The supports can be created using coarser settings. An internal cross hatch structure is generated between the inner and the outer surface boundaries of the part. This serves to hold up the walls and entrap liquid that is later solidified with the presence of UV light. Preparing building parameters for positioning and stepwise manufacturing in the light of many available possibilities can be difficult if not accompanied by proper documentation. These possibilities include determination of the geometrical objects, the building orientation, spatial assortments, arrangement with other parts, necessary support structures and slice parameters. They also include the determination of technological parameters such as cure depth, laser power and other physical parameters as in the case of SLA. It means that user-friendly software for ease of use and handling, user support in terms of user manuals, dialogue mode and online graphical aids will be very helpful to users of the RP system.



1.	X–Y shrink
2.	Z shrink
3.	Number of copies
4.	Multi-part spacing
5.	Range manager (add delete, etc.)
6.	Recoating
7.	Slice output scale
8.	Resolution
9.	Layer thickness
10.	X–Y hatch-spacing or 60/120 hatch spacing
11.	Skin fill spacing (X, Y)
12.	Minimum hatch intersecting angle



2.a) Selective Laser Sintering

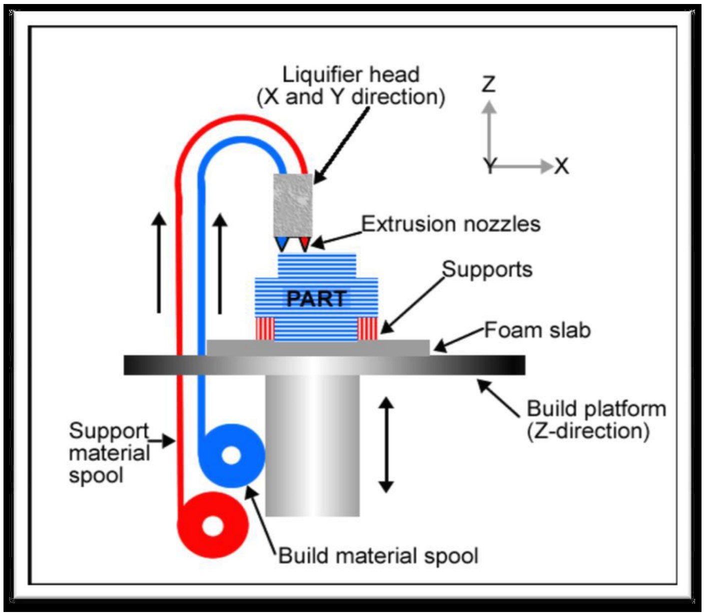


The SLS process is based on the following two principles:

(1) Parts are built by sintering when a CO2 laser beam hits a thin layer of powdered material. The interaction of the laser beam with the powder raises the temperature to the point of melting, resulting in particle bonding, fusing the particles to them-selves and the previous layer to form a solid.

(2) The building of the part is done layer by layer. Each layer of the building process contains the cross-sections of one or many parts. The next layer is then built directly on top of the sintered layer after an additional layer of powder is deposited via a roller mechanism on top of the previously formed layer.

2.b) Fused Deposition Modeling



A geometric model of a conceptual design is created on a CAD software which uses IGES or STL formatted files. It can then imported into the workstation where it is processed through the QuickSlice® and SupportWorkTM propriety software before loading to FDM.

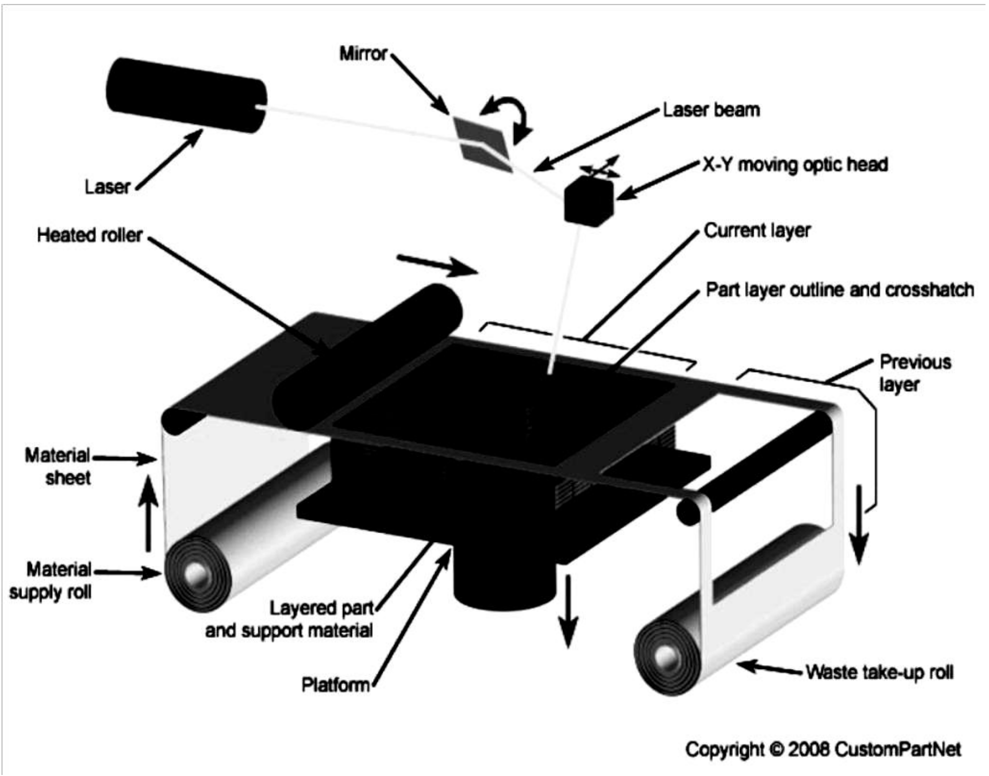
Within this software, the CAD file is sliced into horizontal layers after the part is oriented for the optimum build position, and any necessary support structures are automatically detected and generated. The slice thickness can be set manually to anywhere between 0.172 to 0.356 mm (0.005 to 0.014 in) depending on the needs of the models. Tool paths of the build process are then generated which are downloaded to the FDM machine.

The modeling material is in spools — very much like a fishing line. The filament on the spools is fed into an extrusion head and heated to a semi-liquid state. The semi-liquid material is extruded through the head and then deposited in ultra thin layers from the FDM head, one layer at a time. Since the air surrounding the head is maintained at a temperature below the materials' melting point, the exiting material quickly solidifies.

Moving on the *X–Y* plane, the head follows the tool path generated by QuickSlice® or Insight generating the desired layer. When the layer is completed, the head moves on to create the next layer. The horizontal width of the extruded material can vary between 0.250 to 0.965 mm depending on model.

Two modeler materials are dispensed through a dual tip mechanism in the FDM machine. A primary modeler material is used to produce the model geometry and a secondary material, or release material, is used to produce the support structures. The release material forms a bond with the primary modeler material and can be washed away upon completion of the 3D models.

3.a) LOM Operation



1. Pre-processing phase

The pre-processing phase comprises several operations. The initial steps include generating an image from a CAD-derived STL file of the part to be manufactured, sorting input data, and creating secondary data structures. These are fully automated by LOMSlice, the LOM system software, which calculates and controls the slicing functions. Orienting and merging the part on the LOM system are done manually. These tasks are aided by LOMSliceTM, which provides a menu-driven interface to perform transformations (e.g., translation, scaling, and mirroring) as well as merges.

2. Building Phase

The build cycle has the following steps:

Step 1: LOMSlice creates a cross section of the 3D model measuring the exact height of the model and slices the horizontal plane accordingly. The software then images cross hatches which define the outer perimeter and convert these excess materials into a support structure.

Step 2: The computer generates precise calculations, which guide the focused laser beam to cut the cross sectional outline, the cross hatches and perimeter of the model. The laser beam power is designed to cut exactly the thickness of one layer of material at a time. After the perimeter is burned, everything within the model's boundary is freed from the remaining sheet.

Step 3: The platform with the stack of previously formed layers descends and a new section of material advances. The platform ascends and the heated roller laminates the material to the stack with a single reciprocal motion, thereby bonding it to the previous layer.

Step 4: The vertical encoder measures the height of the stack and relays the new height to LOMSlice, which calculates the cross section for the next layer as the laser cuts the model's current layer.

The above sequence continues till all the layers are built.

3. Post Processing Phase

Step 1: The metal platform, home to the newly created part, is removed from the LOM machine. A forklift may be needed to remove the larger and heavier parts from the LOM

Step 2: Normally a hammer and a putty knife are all that is required to separate the LOM block from the platform. However, a live thin wire may also be used to slice through the double-sided foam tape, which serves as the connecting point between the LOMTM stack and the platform.

Step 3: The surrounding wall frame is lifted off the block to expose the crosshatched pieces of the excess material. Crosshatched pieces may then be separated from the part using wood carving tools.

Applications of LOM:

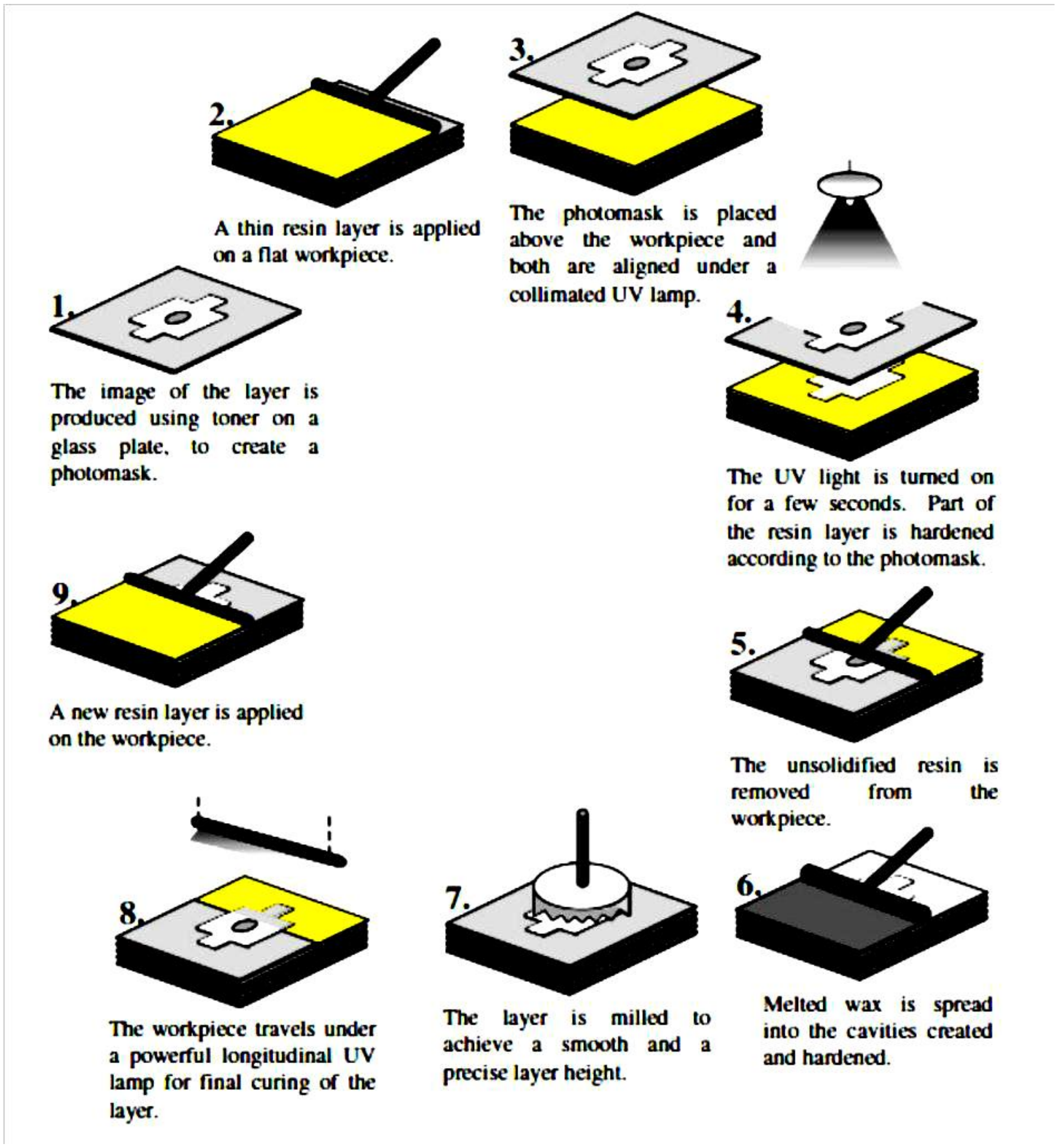
1. *Visualization*. Many companies utilize LOMTM's ability to produce exact dimensions of a potential product purely for visualization. LOMTM part's wood-like composition allows it to be painted or finished as a true replica of the product. As the LOMTM procedure is inexpensive several models can be created, giving sales and marketing executives opportunities to utilize these prototypes for consumer testing, marketing product introductions, packaging samples, and samples for vendor quotations.

2. *Form, fit and function*. LOMTM parts lend themselves well for design verification and performance evaluation. In low-stress environments LOMTM parts can withstand basic tests, giving manufacturers the opportunity to make changes as well as evaluate the aesthetic property of the prototype in its total environment.

3. *Manufacturing*. The LOMTM part's composition is such that, based on the sealant or finishing products used, it can be further tooled for use as a pattern or mold for most secondary tooling techniques including: investment casting, casting, sanding casting, injection molding, silicon rubber mold, vacuum forming and spray metal molding. LOMTM parts offer several advantages

important for the secondary tooling process, namely: predictable level of accuracy across the entire part; stability and resistance to shrinkage, warpage and deformity; and the flexibility to create a master or a mold. In many industries the master created through secondary tooling, or even when the LOMTM part serves as the master (e.g., vacuum forming), withstands enough injections, wax shootings or vacuum pressure to produce a low production run from 5 to 1000 pieces.

3.b) Solid Ground Curing



1. The image of the layer is produced using toner on a glass plate, to create a photomask.

2. A thin resin layer is applied on a flat workpiece.

3. The photomask is placed above the workpiece and both are aligned under a collimated UV lamp.

4. The UV light is turned on for a few seconds. Part of the resin layer is hardened according to the photomask.

5. The unsolidified resin is removed from the workpiece.

6. Melted wax is spread into the cavities created and hardened.

7. The layer is milled to achieve a smooth and a precise layer height.

8. The workpiece travels under a powerful longitudinal UV lamp for final curing of the layer.

9. A new resin layer is applied on the workpiece.

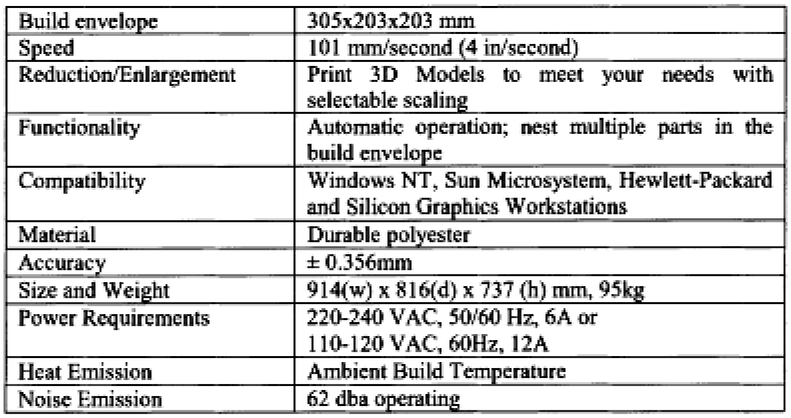
4. a) Thermal jet Ink Printer

The Multi-Jet Modelling (MJM) process was developed by 3D Systems in 1995. This technology complements 3D Systems's established line of Stereo lithography products. Initially, the MJM machine was marketed as the Actua 2100 but since 1998 it has been known as the ThermoJet printer.

MJM parts are constructed from a thermoplastic material. The parts have a layer thickness of 40 /-lm, an X-Y resolution of 85 /-lm and a droplet placement accuracy of ± 100 um.

b) Genisys Xs printer HP System

The process was developed by IBM and is similar to Fused Deposition Modelling. In January 1995, Stratasys purchased this RP technology from IBM and from it developed a Concept Modeller called the Genisys 3D Printer principally for use by design offices**.**



Build envelope	305x203x203 mm
Speed	101 mm/second (4 in/second)
Reduction/Enlargement	Print 3D Models to meet your needs with selectable scaling
Functionality	Automatic operation; nest multiple parts in the build envelope
Compatibility	Windows NT, Sun Microsystem, Hewlett-Packard and Silicon Graphics Workstations
Material	Durable polyester
Accuracy	± 0.356mm
Size and Weight	914(w) x 816(d) x 737 (h) mm, 95kg
Power Requirements	220-240 VAC, 50/60 Hz, 6A or 110-120 VAC, 60Hz, 12A
Heat Emission	Ambient Build Temperature
Noise Emission	62 dba operating

c) Multijet Modelling

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d) Object Quadra system

Objet Geometries Ltd. was founded in 1998 to develop a RP system that employs state-of-the-art ink-jet technology and a proprietary photopolymer.

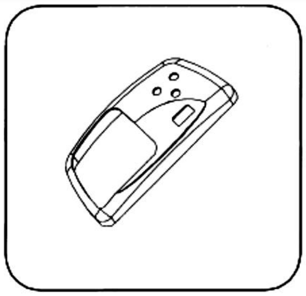
The Objet Quadra process employs 1536 nozzles to build parts by depositing layers of photo sensitive resin that are then fully cured, layer-by-layer, using two UV lights. As previously mentioned, models produced by the system do not require postcuring. The Objet system prints with a resolution of 600 dpi and a layer thickness of 20 /lm. Only one photopolymer is currently available for building models but other materials are under development. To support overhanging areas and undercuts Objet deposits a second material which can be separated easily from the model without leaving any blemishes

PART B

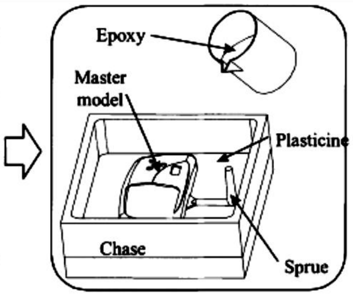
5. a) *Rapid tooling* refers to mold cavities that are either directly or indirectly fabricated using rapid prototyping (RP) techniques.

Aluminum Filled epoxy casting

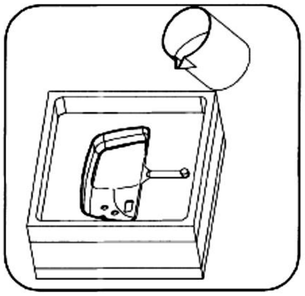
1. The fabrication of the mould begins with the construction of a simple frame around the parting line of the RP model.
2. Sprue gates and runners can be added or cut later on, once the mould is finished.
3. The exposed surface of the model is coated with a release agent and epoxy is poured over the model.
4. Aluminium powder is usually added to the epoxy resin and copper hose cooling lines can also be placed at this stage to increase the thermal conductivity of the mould.
5. Once the epoxy has cured, the assembly is inverted and the parting line block is removed, leaving the pattern embedded in the side of the tool just cast.
6. Another frame is constructed and epoxy poured to form the other side of the tool.
7. When the second side of the tool is cured, the two halves of the tool are separated and the pattern is removed.



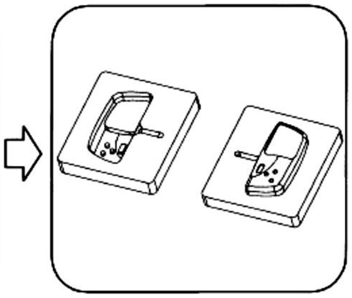
Master model



Embedding of the model along its parting line and backfilling with epoxy resin



Inversion of the first half of the mould and backfilling



Epoxy injection moulding inserts

5c) Cast Kirksite

Originally developed for sheet metal forming tools in the automotive industry, kirksite material is a zinc/aluminum alloy (94 percent Zn, 6 percent Al) with a melting point of 725 ºF. Due to the vapor pressure of the zinc, the material is almost immune to the gas porosity encountered with other alloy systems and the shrinkage is approximately half that of aluminum, resulting in great cast mold accuracy and repeatability. Kirksite is machinable and weldable, making on the fly design adjustments possible. One of the main benefits to this process is the ability to make geometric changes quickly and cheaply. In extreme cases, if required for the application, several iterations of kirksite tools are possible at less cost (in time and money) than one steel tool. Tool life is dependent on many factors, particularly geometric complexity and the nature of the material to be molded. Quantities of fifty to five hundred pieces are typical prototype runs, but quantities as high as two hundred thousand pieces have been molded using cast kirksite dies.

The Design Considerations

Most of the design considerations used in creating injectionmolded parts are the same in prototype part design—including draft, fillets, radii and wall thickness. Parts run in cast kirksite molds generally range in size from a one-inch cube envelope to an approximate twenty-four–inch cube. As with any other tooling method, consideration must be given to process limitations to maximize the success of the product. By introducing a casting process into your tool build, you gain speed, but you must use a slightly wider tolerance band on noncritical dimensions since an additional shrinkage factor must be included. Areas that are critical to function must be identified and that detail can be CNC machined into the mold with great accuracy. Cosmetic appearance expectation must be measured and appearance-critical areas can be enhanced through mold finishing/polishing and appropriately engineered cooling and ejection systems

6.a) Quick cast process

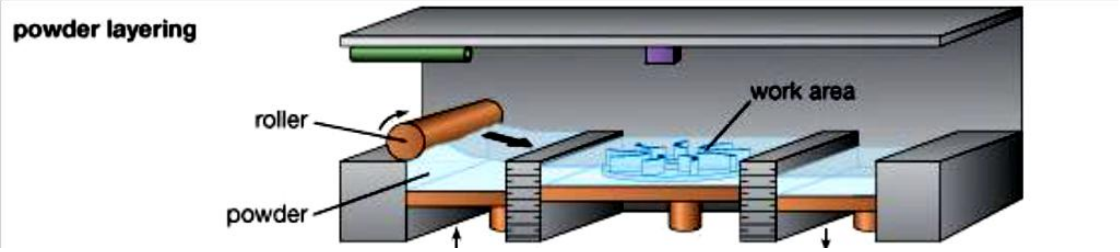
QuickCast, a 3D Systems proprietary process, replaces traditional wax patterns for investment casting with stereolithography (SLA) patterns created in a robust, durable material, without tooling and without delay. The net result is QuickCast patterns in as little as 2 to 4 days and quality metal castings in 1 to 4 weeks.

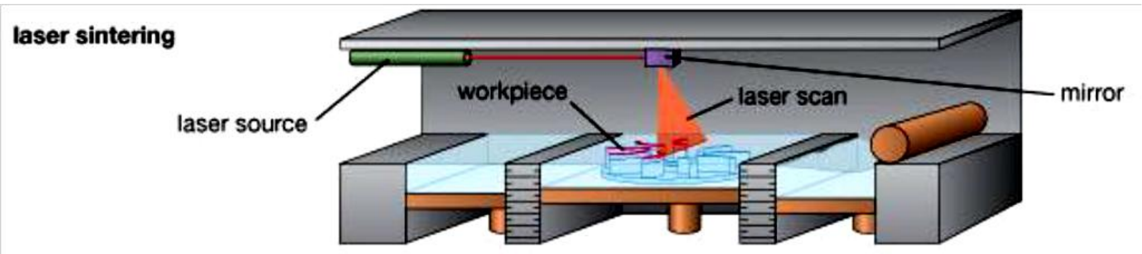
The QuickCast part resembles a beehive hatch pattern and ends up being about 80% hollow. It will burn out in the investment casting process with very little residue. This hollow build style is important, as it allows the pattern to collapse inward during the autoclave and shell burnout phases of the casting process and thus prevents expansion forces from cracking the shell. The mostly hollow build style also reduces the amount of material necessary to burnout.

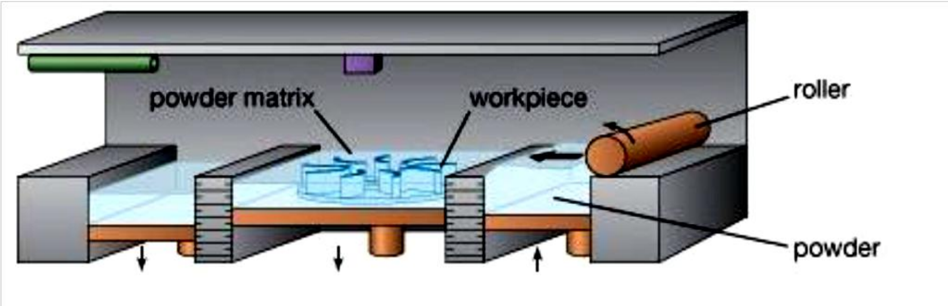
As with wax patterns, QuickCast patterns must be incorporated into a system that includes the pouring cup, sprue, runners and gates.. Creating an assembly with QuickCast patterns is similar to creating an assembly with wax patterns.

b) Direct Metal Laser Sintering Process

Direct metal laser sintering (DMLS) Is an additive manufacturing technique that uses a laser as the power source to sinter powdered material (typically metal), aiming the laser automatically at points in space defined by a 3D model, binding the material together to create a solid structure.







c) Soft tooling and hard tooling

Soft tooling can be used to inject multiple wax or plastic parts using conventional injection-molding techniques.

Traditional *hard-tooling* patterns are fabricated by machining either tool steel or aluminum into the negative shape of the desired component.

The most widely employed indirect **RT** methods are to use RP masters to make silicone room temperature-vulcanising (RTV) moulds for plastic parts and as sacrificial models for investment casting of metal parts.

These processes, which are suitable for batches of 1 to 20 parts, are usually known as "soft tooling" techniques. In spite of the widening of the range of materials allowed by soft tooling, the choice is still limited and not all needs can be satisfied. Therefore, other indirect methods for tool fabrication have been developed. These new methods allow prototypes to be built using the same material and manufacturing process as the production part.

7. a) i) STL file

STL (Standard Tessellation Language) is a file format native to the stereolithography CADsoftware created by 3D Systems. This file format is supported by many other software packages; it is widely used for rapid prototyping and computer-aided manufacturing. STL files describe only the surface geometry of a three dimensional object without any representation of colour, texture or other common CAD model attributes. The STL format specifies both ASCII and binary representations. Binary files are more common, since they are more compact.

An STL file describes a raw unstructured triangulated surface by the unit normal and vertices (ordered by the right-hand rule) of the triangles using a three-dimensional Cartesiancoordinate system.

This format has long been the industry standard in rapid prototyping. Let_s look into the process of approximating surfaces with triangles: Each 3D form is made out of polygons. A polygon is defined as a flat shape which is bounded by a closed circuit. Each polygon with nsides can be represented using n-2 triangles.

ii) Magics Software

Magics is rapid prototyping software and is a key element of the Magics e-Solution Suite, a full range of market-leading software products that will streamline, automate and boost almost every step in your rapid prototyping and manufacturing (RP&M) process.

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.

iii) Mimics Software

For the first time, doctors, nurses, and technicians who have no previous experience with 3D modelling or 3D printing can create 3D anatomical models from MRI and CT scan images quickly and easily.

Developed by Materialise (creator of Mimics, the leading medical imaging software for the rapid prototyping industry), Mimics Z™ is optimized for output on 3D Systems high-definition, 3D printers that produce full-colour models in only hours. Healthcare organizations worldwide increasingly rely on 3D anatomical models for pre-operative planning, specialist consultation, implant fit and design, patient counselling and medical education.

iv) Magics Communicator

Visualise

View STL, IGES*, VDA* and DXF 3d faces*, with fast rotation, zooming and cross sectioning.

Annotate

Add 2D and 3D annotations, shapes, text and bitmaps.

Measure

Easily create 2D drawings from 3D files. Extensive feature recognition allows measuring of distances, radii and angles in 3D. Add tolerances and additional info.

Present

Make a 3D slide show with adjustable colours, shading and transparency.

Ease of use

Communicator's straightforward interface ensures that even non-CAD users will be comfortable with the program in no time.

b) Other software tool

SolidView software allows non-CAD users to easily **view**, **measure**, **translate** and **markupCAD data**, opening up communication to all who need to be involved in the design process. SolidView is used across the world by those needing access to CAD data but not trained in using CAD systems. It‗s a low-cost solution to access CAD data for manufacturing engineers, scientists, structural engineers, technical illustrators, managers, product managers and sales people.

8.a) Factors influencing part accuracy

The factors that influence RP process accuracy can be considered in 3 groups
I. Factors causing errors during the data preparation stage like STL file generation model slicing and part build orientation.

II. Factors influencing the part accuracy during the build stage such as process specific parameters.

III. Factors which are directly related the other part finishing technique employed

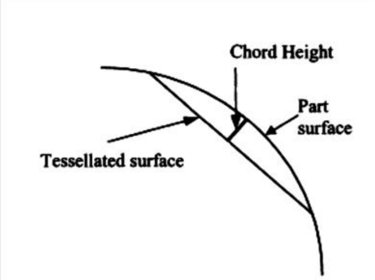
Data preparation

1. Errors due to tessellation
a. Chord height
b. Angle control
2. Errors due to slicing

Errors due to tessellation

Most RP systems employ standard STL input files. A STL file approximates the surface of the 3D CAD model by triangles. Errors caused by tessellation are usually ignored because of the belief that tessellation errors can be minimized by increasing the number of triangles. However, in practice the number of triangles cannot be increased indefinitely. The resolution of STL files can be controlled during their generation in a 3D CAD system through tessellation parameters.

Chord Height. This parameter specifies the maximum distance between a chord and surface (Figure 1). **If** less deviation from the actual part surface is required, a smaller chord height should be specified. The lower bound for this parameter is a function of the CAD model accuracy. The upper bound depends on the model size.



Angle Control. This parameter specifies the required definition level along curves with small radius. Specifically, it defines a threshold for the curve radius (ro) below which the curves should be tessellated:

Errors due to slicing

RP processes have a stair-stepping problem that is found in all layer manufacturing technologies. Stair-stepping is a consequence of the addition of material in layers. As a result of this discrete layering, the shape of the original CAD models in the build direction (z) is approximated with stair-steps. This type of error is due to the working principles of RP processes, which can be assessed in data preparation.

The stair-steps particularly affect slight slopes. This problem influences mainly the roughness of the part and can be alleviated by reducing the thickness of the layers. However, layer thickness cannot be indefinitely decreased and a compromise has to be found between thickness and build speed.

8b) Part Building Errors

There are two main types of errors in the part building process, namely curing errors and control errors. Curing errors refer to those errors that are caused by over-curing and scanned line shape. Control errors are those errors caused by layer thickness an scan position control. Both types of errors affect part accuracy.

Over-curing. Laser over-curing is necessary to adhere layers to form solid parts. However, it causes dimensional and positional errors to features. The overcured material in the bottom layer can be seen in Figure 4a, from which the unusual thickness of the bottom layer can be noted. This causes a dimensional change in the z direction along the lower feature boundary. As a result, the feature shape is deformed and the feature centre position is shifted. Figure 4b shows part of a deformed boundary of what should have been a circular feature.

Scanned line shape. A scanned line is created when a laser beam scans the resin surface. The cross section of the scanned line is referred to as the scanned line shape. A cross section is shown in Figure 9.8. Note that the shape deviates from the theoretically predicted parabola. The actual shape is determined by the properties of the resin and laser. The part building process is assumed to be a stacking up of rectangular shaped blocks. However, the actual process employs different shaped blocks. As a result of the shape of scanned lines, a supposedly vertical edge is not a straight line, but is rather jagged.

Control errors. Theoretically, the layer thickness should be at the defined value and the border line should be positioned at the specified positions. In fact, the layer thickness is variable and the border position is not precise.

Part Finishing errors

The model accuracy after finishing operations is influenced mostly by two factors, the varying amount of material that has to be removed and the finishing technique adopted. These two factors determine to what extent the dimensional accuracy of RP models will be reduced during finishing.

Varying amount of material. During the data preparation stage, the RP model shapes are approximated with the comers of the stair-steps. Each RP process reproduces the comers and the stair-steps with a different resolution. Hence, the amount of material that has to be removed to improve the surface finish will vary depending on the RP process employed. Also, the amount of material to be removed on surfaces of the same model can vary due to the selected part build orientation.

Finishing technique. A number of processes can be employed to finish RP models, for example, wet and dry sanding, sand blasting, coating, spraying, infiltration with special solutions, machining, etc. Each technique has specific technological capabilities and can be characterised by the achievable dimensional accuracy and surface roughness. The techniques that assure better dimensional control during the finishing operation will have less impact on model accuracy.