UNIT – 2

Rapid Prototyping

Contents

Important Repeated Questions:

1. Explain the need/importance of Rapid Prototyping. (S23 - Q4a, 03; W24 - Q4a, 03)
2. Explain Fused Deposition Modelling (FDM) process in detail with neat sketch/advantages/disadvantages/applications. (S23 - Q4c, 07; W23 - Q4c, 07; W22 - Q4c, 07; W24 - Q4c, 07)
3. Explain Stereo Lithography (SLA) process in detail with neat sketch. (W23 - Q4c, 07; S22 - Q3c, 07; W22 - Q4b, 04)
4. Explain Laminated Object Manufacturing (LOM) process in detail with neat sketch/advantages/disadvantages/applications. (W25 - Q4c OR, 07; S23 - Q4c OR, 07; W22 - Q4c, 07)
5. Write advantages/disadvantages of Rapid Prototyping. (S23 - Q4a OR, 03; W22 - Q4a, 03; S25 - Q4a, 03)
6. Write differences between Additive and Subtractive Manufacturing. (W25 - Q4a, 03; S23 - Q4b, 04; W24 - Q4b, 04)
7. Classify the RP processes. (S25 - Q4a, 03; W23 - Q4b, 04)
8. What is prototyping? Enlist advantages of Rapid Prototyping. (W23 - Q4a, 03; W22 - Q4a, 03)
9. Write applications of Laminated Object Manufacturing (LOM) processes. (W23 - Q4b, 04; W22 - Q4b, 04)

Legends: W- Winter, S- Summer, Q- Question and 03/04/07- Marks of Question

2.1 Introduction

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.

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.

2.2 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.

Table 2.1 - Traditional Prototyping Vs Rapid Prototyping

Traditional Prototyping	Rapid Prototyping
It could include building a model from CLAY, carving from wood, bending wire meshing etc.	It could include building a model from thermoplastic, photopolymer, metals, paper, titanium alloys etc.
These methods are time consuming.	These methods consume less time.
Lack the quality to serve its purpose.	Gives better quality.
It can't effectively evaluate the alternative design concepts in the product definition stage.	It can effectively evaluate the alternative design concepts in the product definition stage.
Generally these methods are performed manually.	Generally these methods are performed automatically.
Increases product launch time.	Reduces product launch time.

2.2.1 A Typical Rapid Prototyping Process

There are many different RP processes, but the basic operating principles are very similar. *Fig.2.1* shows the data-flow diagram of the basic process.

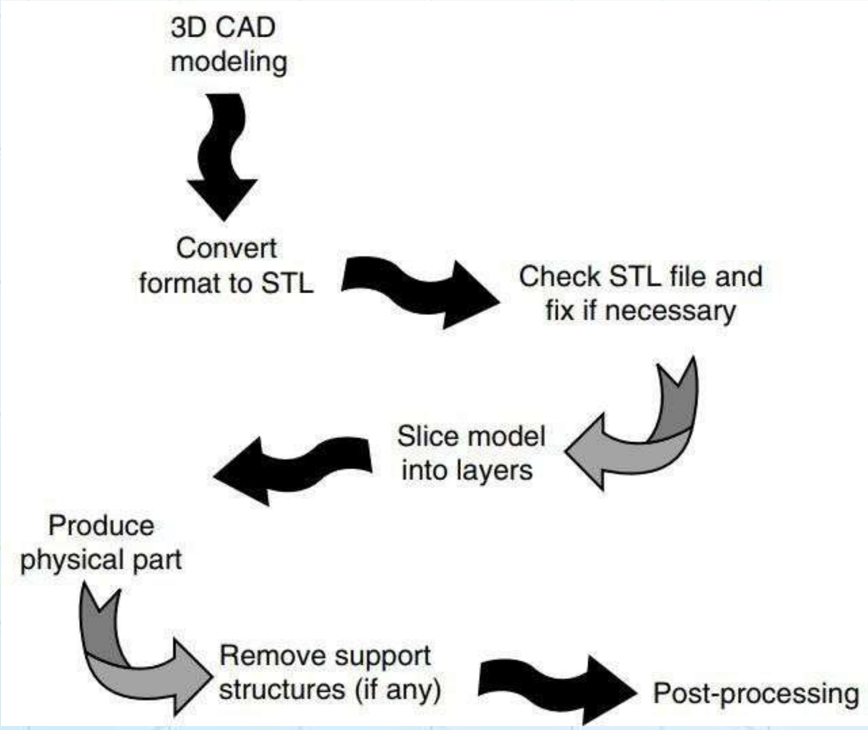

Fig.2.1 – The data flow of the basic RP process

It includes the following steps:

- 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.

(1) 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.

(2) 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.

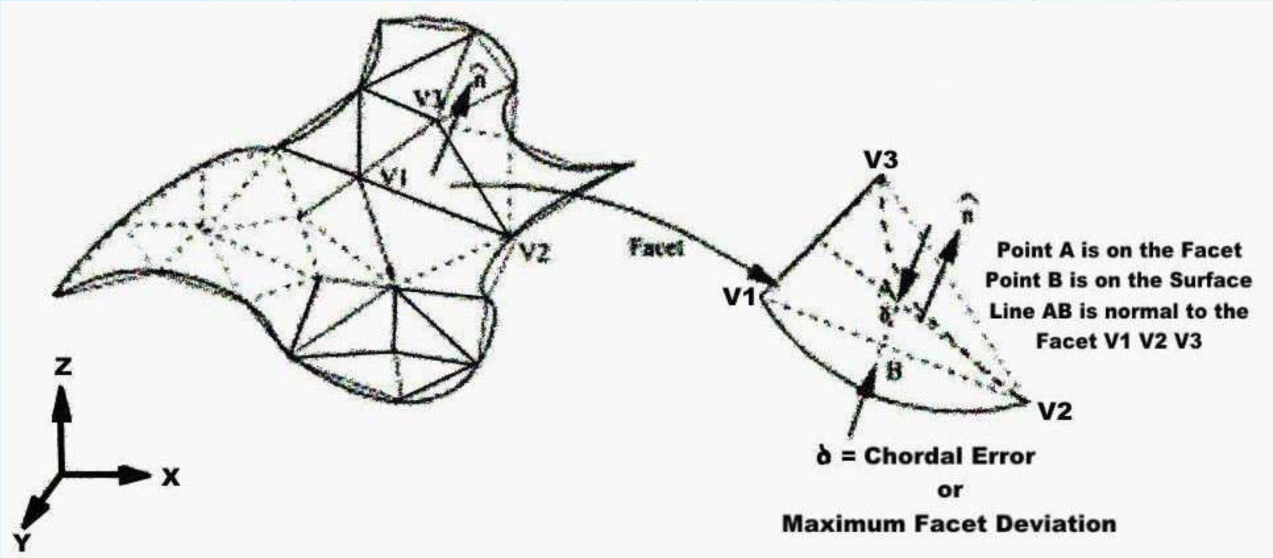

Fig.2.2 – Tessellation defects

(3) 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

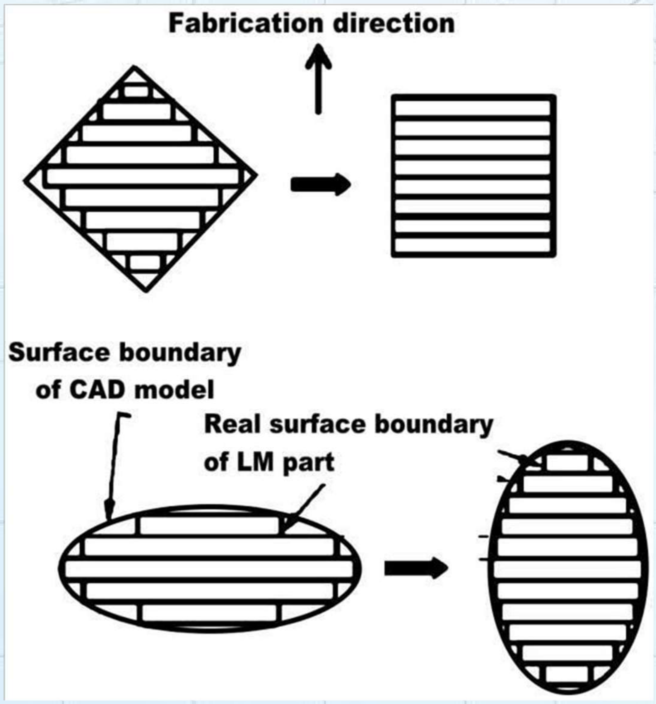

Fig.2.3.

Fig.2.3 – 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.

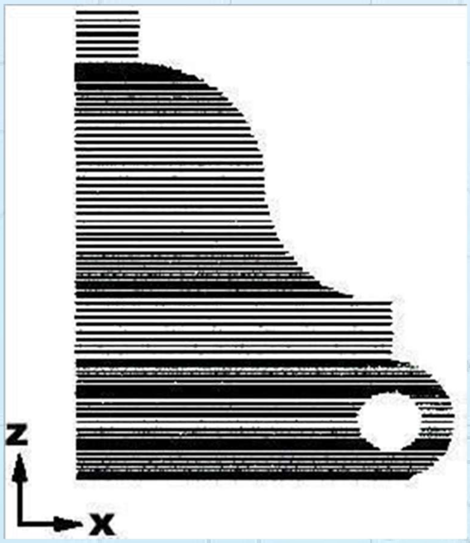

Fig.2.4 – Slicing

(4) 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.

(5) 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.

(6) 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.

2.3 Data Preparation and Data Files

- The industry standard for rapid prototyping is the STL file, a file extension from STereoLithography.
- Basically, it is a file that uses a mesh of triangles to form the shell of the solid object, where each triangle shares common sides and vertices. The CAD software generates a tessellated object description.
- In STL format, the file consists of the X, Y, and Z coordinates of the three vertices of each surface triangle, with an index to describe the orientation of the surface normal.
- Normally, the support structure is generated before slicing to hold overhanging surfaces during the build.
- Most current CAD packages can export a CAD file in STL file format, and good STL files will assure a speedy quote turnaround, and good quality RP models. The STL format is an ASCII or binary file used in the RP process.
- It is a list of triangular surfaces that describe a computer-generated solid model. The binary files are smaller when compared to ASCII files.
- The facets define the surface of a 3D object. As such, each facet is part of the boundary between the interior and the exterior of the object.
- The orientation of the facets (which way is ‘‘out’’ and which way is ‘‘in’’) is specified redundantly in two ways that must be consistent.
- First, the direction of the normal is outward. Second, the vertices are listed in counterclockwise order when looking at the object from the outside (right-hand rule) as shown in below figure.

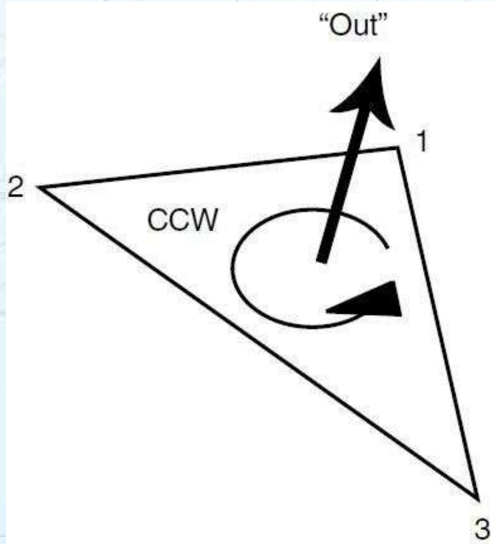

Fig.2.5 – A triangle with three vertices. The sequence of the storage of the vertices indicates the direction of the triangular face

Why STL files?

- The STL files translate the part geometry from a CAD system to the RP machine.
- All CAD systems build parts and assemblies, store geometry, and generally do many things in their own independent and proprietary way.
- Instead of having a machine that has to communicate with all of these different systems, there is a single, universal file format that every system needs to be able to produce so that an RP machine can process what a part looks like for slicing. This is the STL file.
- Why is STL format used? The reason is because slicing a part is easier compared to other methods such as B-rep (boundary representation) and CSG (constructive solid geometry), which will need geometric reasoning and data conversion.
- Below figure shows the representation of a cube in B-rep.

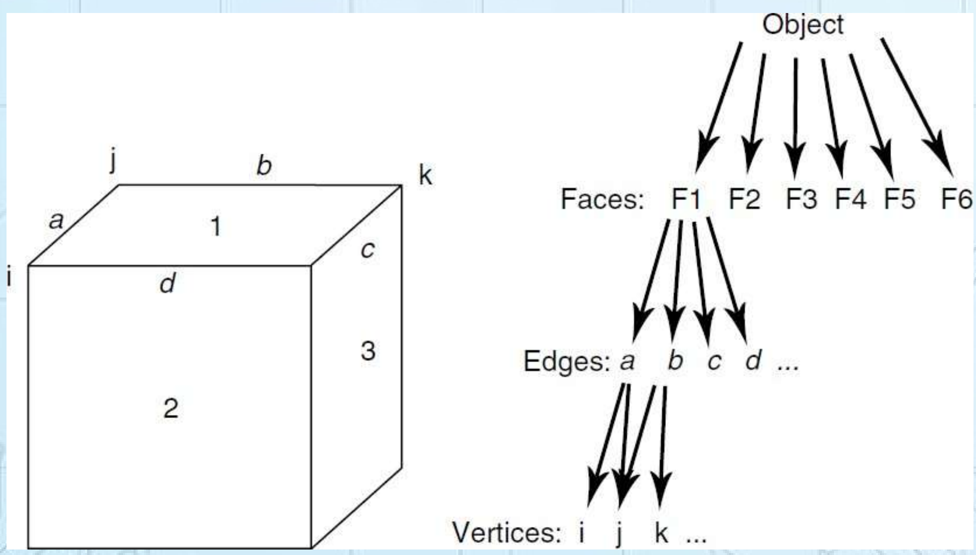

Fig.2.6 – Boundary representation of a cube and its data structure

- The right-hand side of the *Fig.2.6* shows the data structure of the geometric entities.
- To calculate the interaction between the geometry and a plane that represents the slicing operation is not very efficient.
- The slicing operation is computed by ''intersecting'' a ray of virtual lines with the object of interest. In other words, it is necessary to compute the intersections between a lot of lines and the object.
- The STL format allows us to transfer the slicing operation into a routine of finding the interactions between lines and triangles.
- Basically, this operation judges whether the intersection point is within or outside the triangles, and there are very efficient codes to do just that.
- The reason that the STL format is the industry standard is because it can make the process robust and reliable to get the correct result the first time, and because high-end data processing tools, such as surface and STL repair and translation tools, are available in the market.
- The model presenting the physical part to be built should be presented as closed surfaces that define an enclosed volume.
- The meaning of this is that the data must specify the inside, outside, and boundary of the model. This requirement is redundant if the modeling used is solid modeling.
- This approach ensures that all horizontal cross-sections essential to RP are closed curves.
- The internal representation of a CAD model as shown in the below figure can be in B-rep or CSG representations, while its STL representation is shown in the *Fig.2.8*.

Fig.2.7 – CAD model

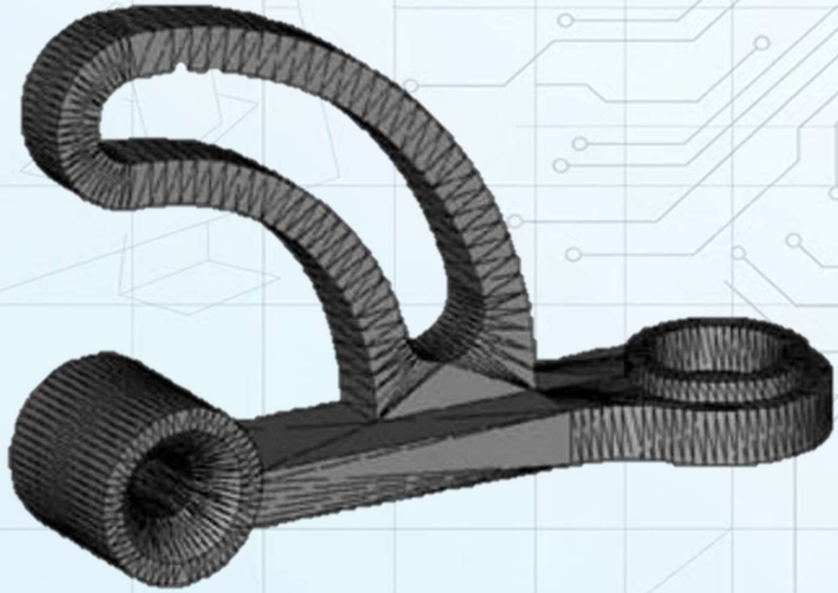

Fig.2.8 – An example of an STL triangulation model

- The STL representation is often used as the standard format to interact between the CAD model and an RP machine.
- The STL representation approximates the surfaces of the model by polygons, meaning that STL files for curved parts can be very large in order to represent the original geometry well.
- In other words, the CAD models can have smooth curved surfaces, but the RP process must have the model broken down into discrete volumes to build the part.
- To have a continuous smooth curved surface, the volumes for each discrete piece would have to be close to zero, which would require the number of entities to be infinite, which makes for a very large file size in the real world.
- In order to minimize the file size to something that is more manageable, the system makes the volumes of the discrete pieces larger.
- The larger these volumes, the fewer are needed to approximate the part. Keep in mind that the fewer the pieces used, the less accurate the approximation is when compared to the original model.
- Triangulation, as shown in figure, is breaking the model into these discrete pieces and the trick is balancing the number and size of these pieces to make a practical file size without sacrificing too much accuracy.

2.4 History of Rapid Prototyping

- 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.

2.5 Applications

- Most of the RP parts are finished or touched up before they are used for their intended applications. Applications can be grouped into
- Historical Developments
- Rapid Tooling
- To Support Medical Applications
- Surgical and Diagnostic Aids
- Prosthetics Development
- Manufacturing
- Tissue Engineering and Organ Printing
- Aerospace Applications
- Automotive Applications
- Reverse Engineering
- Direct Tooling
- Jewelry Design
- Patterns for Casting
- Molds for Casting
- Patterns for Casting
- Validation of Invention
- Wind Tunnel Testing

2.6 Growth of RP Industry

While the RP industry continues to grow, the rate of growth has been flat for the last few years due to the lethargy in the overall economy. In spite of this, over the last few years, established RP companies released new technologies, new materialso and new applications. *Fig.2.9* shows the growth of rapid prototyping since 1988. Sales for 2004 and 2005 are forecasts.

Increase in RP Models Worldwide RP users are producing more and more RP models. In 2001, 3.55 million models or prototypes were produced, up 18.3% from 3 million units made in 2000, according to Wohler's Repon 2004. The growth of RP models is charted in *Fig.2.10*.

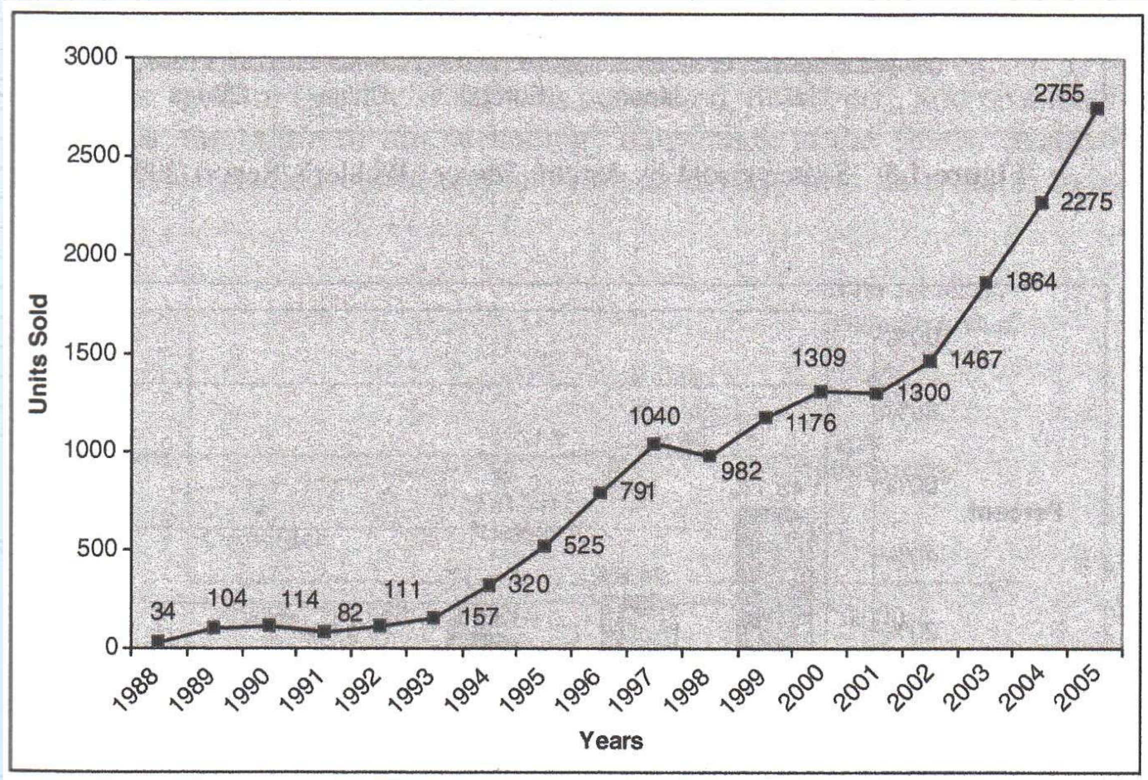

Fig.2.9 – Growth of rapid prototyping. Source: Wohler's Report 2004.

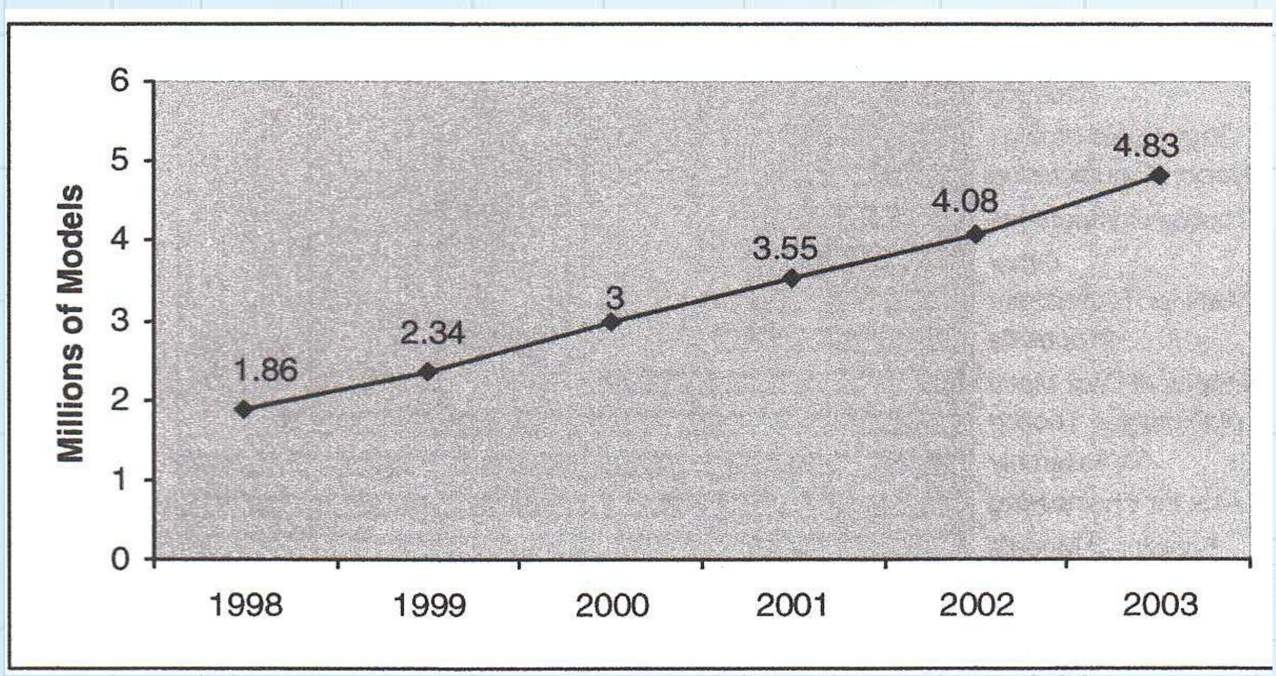

Fig.2.10 – Growth of RP models. Source: Wohler's Report 2004

Sales of RPs by Regions Although RP is a worldwide phenomenon, U.S. manufacturers account for 80% of the unit sales, followed by Japan (11.3%), Europe (4.9%), and others (2.4%).

Units Sold by U.S. Companies Among the U.S. manufacturers of RP equipment, 3D Systems has been the leader in the industry since the beginning. Since its recent acquisition of DTM System, it became an even more dominant company in the United States. With combined sales of 415 units sold in 2001, 3D Systems

controls 40% of the unit sales in the United States, followed by Stratasys, which sold 277 units. For cost-conscious companies, all major RP companies have developed low-cost RP machines such as ThermoJet (3D Systems), 7400 (Z Corp.), and Dimension (Stratasys). The low-cost machines are like concept modelers that are used for concept verification, form, fit, and function, and early verification of design errors and are compatible with an office environment.

2.7 Classification of RP Systems

The most widely accepted means of categorizing RP systems in the industry is by determination of the initial form of the raw material. Accordingly, all RP systems can be categorized into solid-based, liquid-based, and powder-based systems.

2.7.1 Liquid-based RP systems

- Liquid-based RP systems have the initial form of its material in liquid state.
- Through a process commonly known as curing, the liquid is converted into the solid state.
- The following RP systems fall into this category:
  1) 3D Systems' **Stereolithography Apparatus (SLA)**
  2) Cubital's **Solid Ground Curing (SGC)**
  3) Sony's **Solid Creation System (SCS)**
  4) CMET's **Solid Object Ultraviolet-Laser Printer (SOUP)**
  5) Autostrade's E-Darts
  6) Teijin Seiki's Soliform System
  7) Meiko's Rapid Prototyping System for the Jewelry Industry
  8) Denken's SLP
  9) Mitsui's COLAMM
  10) Fockele & Schwarze's LMS
  11) Light Sculpting
  12) Aaroflex
  13) Rapid Freeze
  14) Two Laser Beams
  15) Microfabrication

2.7.2 Solid-based RP systems

- Except for powder, solid-based RP systems are meant to encompass all forms of material in the solid state.
- In this context, the solid form can include the shape in the form of a wire, a roll, laminates and pellets.
- The following RP systems fall into this definition:
  1) Cubic Technologies' **Laminated Object Manufacturing (LOM)**
  2) Stratasys' **Fused Deposition Modeling (FDM)**

3) 3D Systems' **Multi-Jet Modeling System (MJM)**

4) Kira Corporation's **Paper Lamination Technology (PLT)**

5) Solidscape's ModelMaker and PatternMaster

6) CAM-LEM's CL 100

7) Ennex Corporation's Offset Fabbers

8) Beijing Yinhua's Slicing Solid Manufacturing (SSM), Melted Extrusion Modeling (MEM) and
Multi-Functional RPM Systems (M-RPM)

2.7.3 Powder-Based RP systems

- In a strict sense, powder is by-and-large in the solid state.
- However, it is intentionally created as a category outside the solid-based RP systems to mean powder in grain-like form.
- The following RP systems fall into this definition:

1) 3D Systems's **Selective Laser Sintering (SLS)**

2) Precision Optical Manufacturing's **Direct Metal Deposition (DMD)**

3) Z Corporation's **Three-Dimensional Printing (3DP)**

4) Optomec's **Laser Engineered Net Shaping (LENS)**

5) Acram's **Electron Beam Melting (EBM)**

6) Soligen's Direct Shell Production Casting (DSPC)

7) Fraunhofer's Multiphase Jet Solidification (MJS)

8) Aeromet Corporation's Lasform Technology

9) EOS's EOSINT Systems

10) Generis' RP Systems (GS)

11) Therics Inc.'s Theriform Technology

12) Extrude Hone's Prometal 3D Printing Process

- Following *Table 2.2* shows some important RP systems and materials used for that particular technology.

Table 2.2 - RP systems and related base materials

Prototyping Technologies	Base Materials
Selective laser sintering (SLS)	Thermoplastics, Metals powders
Fused Deposition Modeling (FDM)	Thermoplastics, Eutectic metals
Stereolithography (SLA)	Photopolymer
Laminated Object Manufacturing (LOM)	Paper

2.8 Stereo Lithography Systems (SLA)

When a light of appropriate wave length falls on liquid photopolymer, the energy absorbed causes polymerization. The polymerized photopolymer will be in solid state. Laser light is used. When it is scanned on the selected region over a layer of liquid polymer, that region become solid. The remaining liquid can be drained.

Laser beam is positioned using a small mirror capable of deflecting in two directions. Therefore, this has very low inertia and hence high speed and accuracy. The power of the laser decides the layer thickness. Explicit support structures are required. This is achieved by modifying the geometry of the prototype. Typically bristles and thin structures are added.

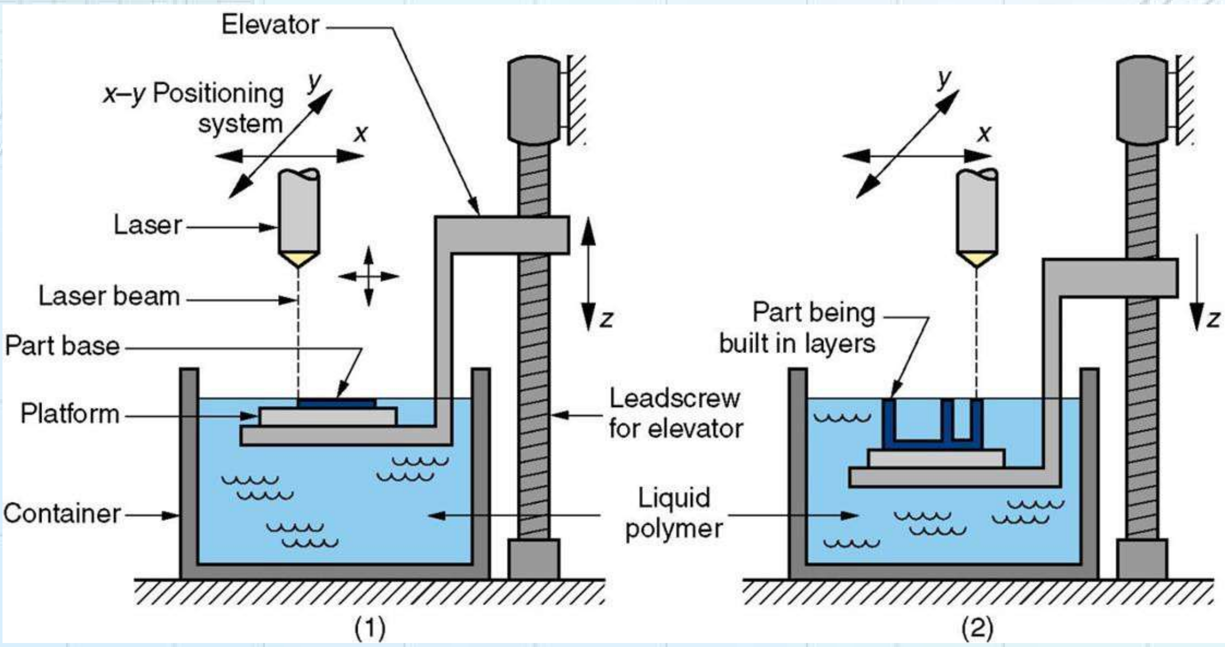

Fig.2.11
1. At the start of the process, in which the initial layer is added to the platform
2. After several layers have been added so that the part geometry gradually takes form

Steps

- Support structures are automatically added to the model wherever required.
- Slicing is done.
- Each slice or layer is realized using the following steps:
- The table (called vat) dips and comes up to the required Z level.
- A blade wipes off the excess liquid.
- The beam scans the liquid layer. For each loop, the border is made and then area filling is done. Area filling is not in zig-zag pattern but in grids.
- After all layers are made, the table rises completely revealing the part.
- After the liquid has drained, it is removed from table and the support structure is carefully cut off.
- The part is kept in a post-cure apparatus where it is kept under UV radiation for an hour or so. This completes polymerization.
- The part is finished and painted as required.

2.9 Selective Laser Sintering (SLS)

- It is developed by University of Texas, Austin.
- It is marketed by DTM, USA and EOS, Germany. Raw material is powder. Principle is similar to Powder Metallurgy but for the absence of compaction. Green part is prepared on the RP machine after partial sintering and sintering is completed inside another furnace.
- Just as SLA, here also laser light is used. When it is scanned on the selected region over a layer of powder, the particles in that region fuse together. The remaining powder acts as support as in the case of LOM.
- Laser beam is positioned using a small mirror capable of deflecting in two directions. Therefore, this has very low inertia and hence high speed and accuracy.
- The power of the laser decides the layer thickness.
- Explicit support structures are not required.
- A wide variety of powders can be used.

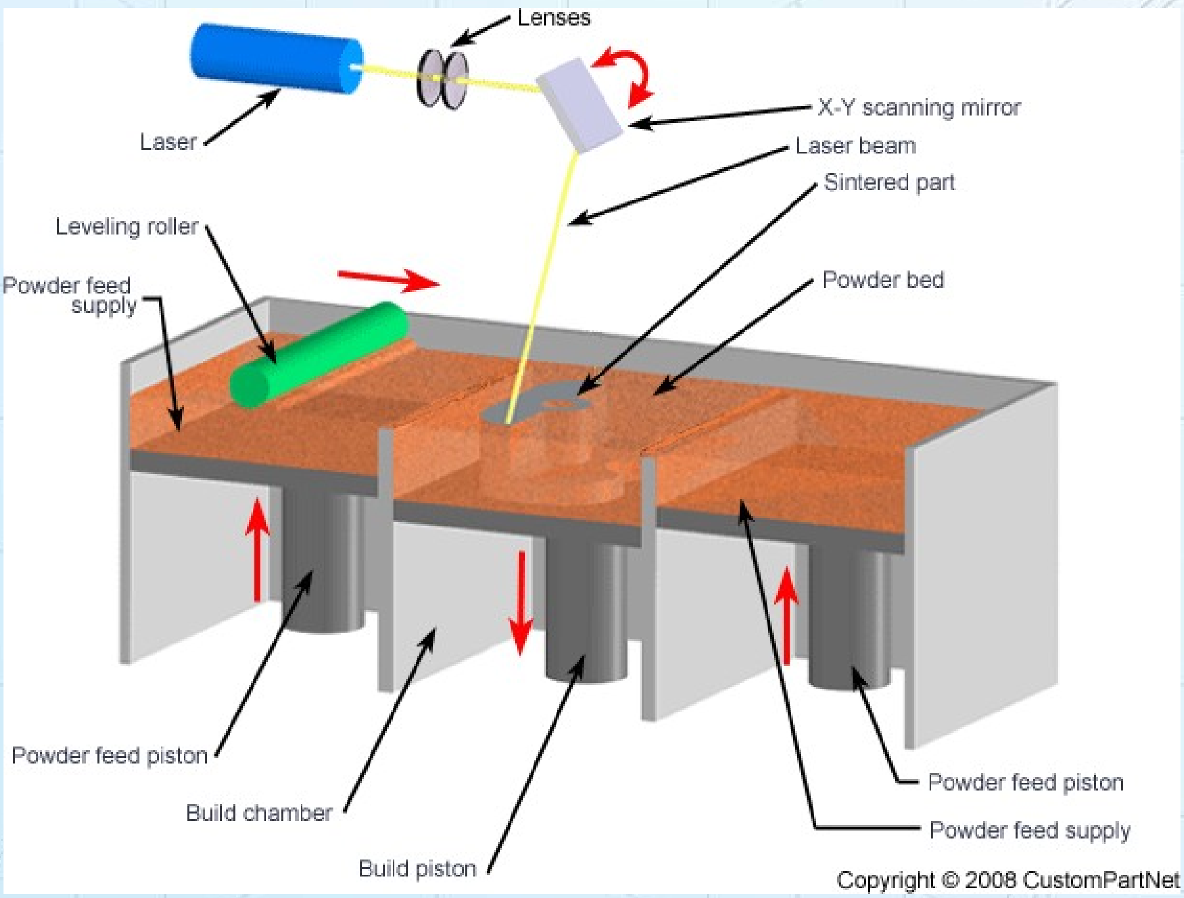

Fig.2.12 – Selective Laser Sintering

Steps

- When the slicing is done, The working volume is maintained with appropriate temperature so that laser supplies the energy required to cross the threshold sintering temperature. An inert environment is created using continuous supply of gas such as Nitrogen. This is to minimize fire harards as the fine particles have high activation.

- Each slice or layer is realized using the following steps:
- The table dips by a layer thickness.
- A layer of powder is spread and leveled using a contra-rotating roller.
- The beam scans the layer of powder. Thus, the required region is “selectively sintered”.
- After all layers are made, the table rises completely revealing a block of cake with the part inside.
- The surrounding powder is soft and it is removed using suitable brushes. This powder is reusable.
- The part is kept in a suitable hot chamber to complete the sintering.
- The metallic prototypes require copper impregnation in another furnace to improve their polishability.
- The part is finished and painted as required.

Advantages

- A wide variety of powders can be used.
- Fast due to tiny moving mirror parts as in SLA.
- Metallic parts can be made.
- Suitable for making injection molding tools.

Limitations

- Surface finish is less and dictated by the particle size.
- Z accuracy is poor due to the absence of milling.

2.10 Fused Deposition Modelling (FDM)

This is a very sophisticated version of ‘Jilebi (in Hindi)‘, ‘chakli (in Hindi)‘, Murukku (in Tamil)‘ or ‘vermicelli (in English?)‘ making process.

Molten material inside a hot chamber is extruded through a nozzle. Use of the raw material in wire form as a consumable piston is a great idea. he nozzle size alone does not decide the layer thickness and roadwidth. They together depend on speed of head and wire feed speed. Their relation can be obtained from the principle of conservation of mass. (Analogy: applying tooth paste on the brush.)

Explicit support structures are required. Therefore, twin heads are used, one for model and the other for support.

Steps

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

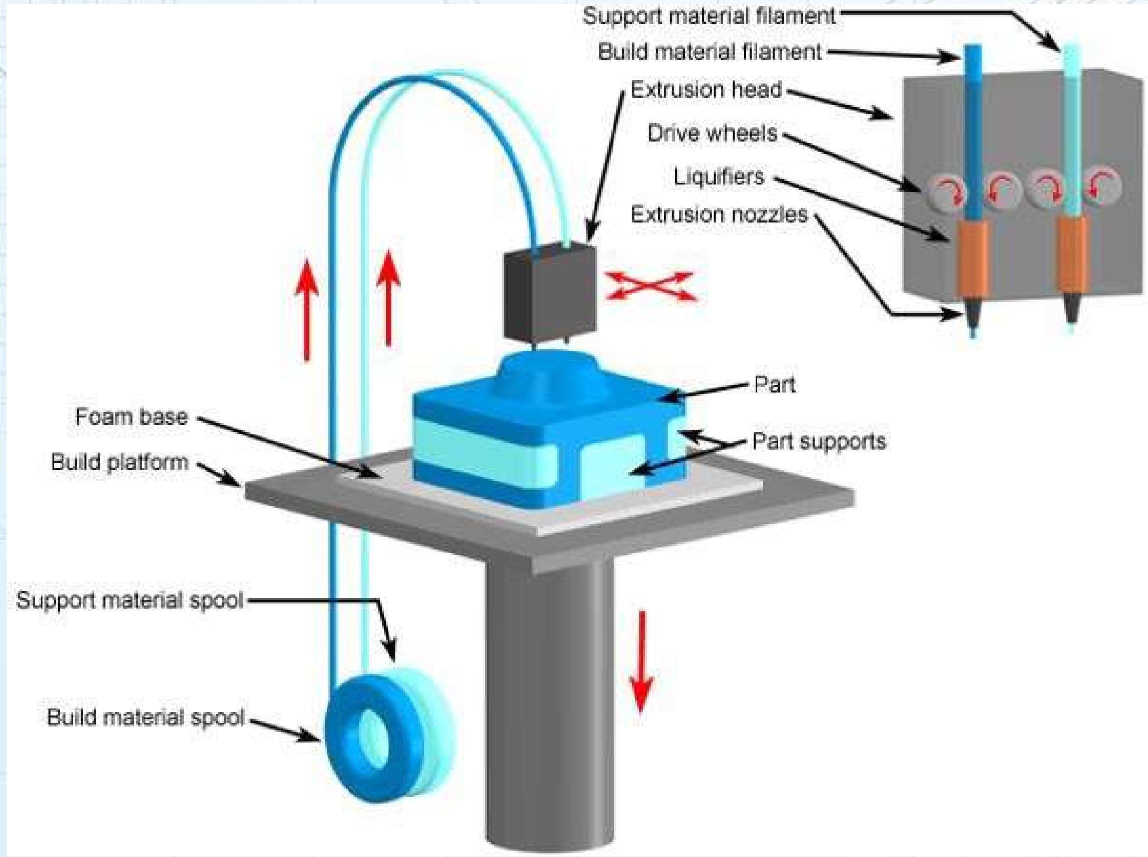

Fig.2.13 – Fused Deposition Modelling

Advantages

- Any thermoplastic material can be used as long as the appropriate head is available.
- It does not employ lasers and hence no safety related issues. It does not use liquid/ powder raw materials and hence clean. It can be kept in an office environment as a 3D printer.
- Very easy to remove the support. This is probably the easiest of all RP processes.
- This is the cheapest machine. However, this is also due to their business policy since the costs of all RP machines are comparable.

Limitations

- As every point of the volume is addressed by a „mechanical device", it is very slow.
- Not very accurate compared SLA, SGC etc.
- Not isotropic.

2.11 Laminated Object Manufacturing (LOM)

There are two approaches of LOM process.

I. **Cut and then paste**
    - Handling the cut pieces is difficult if not impossible since
    - A support mechanism will be required.
    - Suitable for laminated tooling.

II. **Paste and then cut**

- Handling is easy – indexing of the reel is all that is required.
- The remaining stock acts as the support material.
- The only drawback is the time-consuming decubing operation.
- Suitable for paper-like flexible materials.

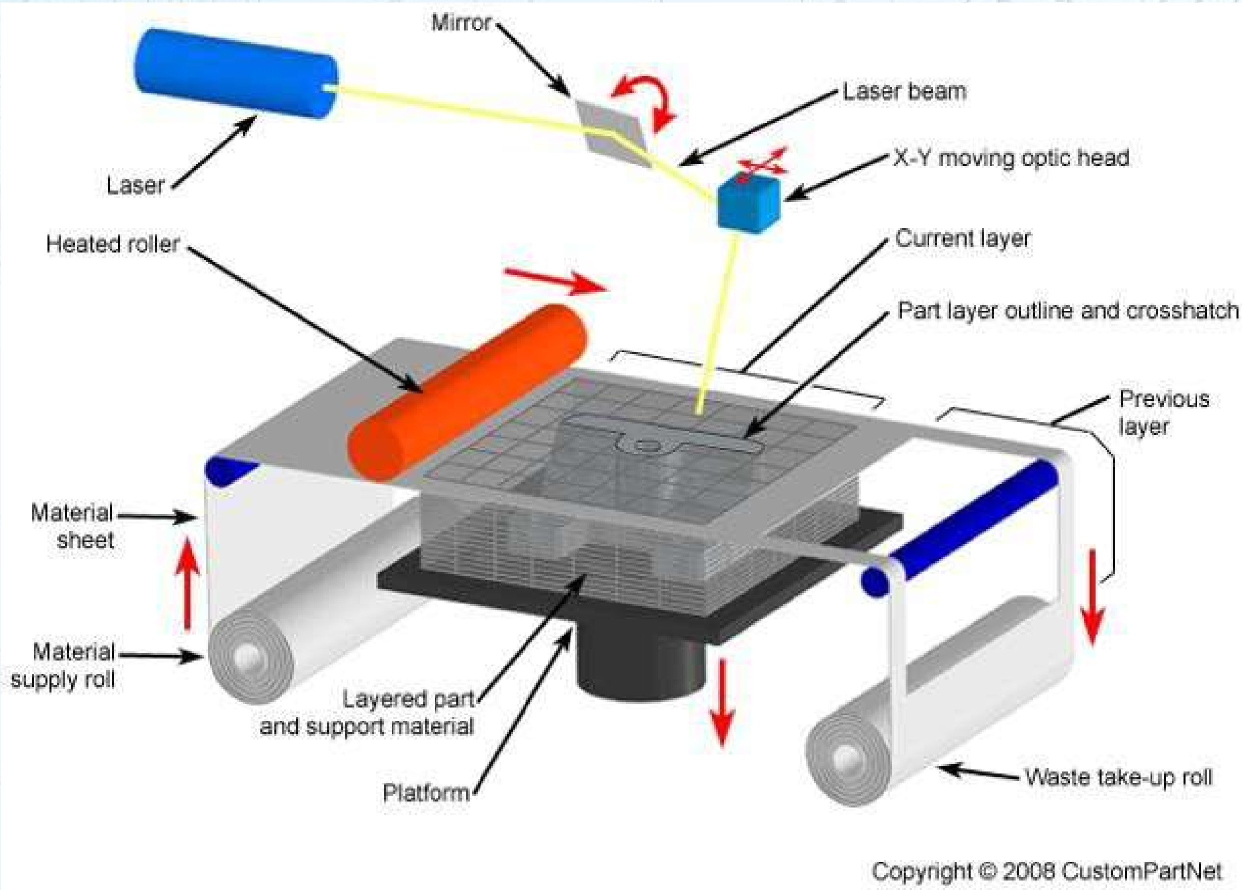

Fig.2.14 – Laminated Object Manufacturing (LOM) process

Steps

- If multiple parts are to be made, one has to arrive at a cluster of optimal packing (an automatic program for this is still not available!). It is preferable to pack as many pieces as possible in processes such as LOM, SLS, SGC and 3DPrinitng.
- The object/ cluster is positioned and oriented in the desired place. Some users tilt it by 10 to 15 deg. to avoid any surface becoming horizontal (why?).
- Set the machine with the desired process parameters such as beam diameter, beam offset flag, grid sizes, number of dummy layers, bridging gap between two cuts etc.
- Load the paper roll of appropriate width.
- Identify the location for the build on the table and feed it to the machine. Paste a double-sided adhesive in that zone.
- Each slice or layer is realized using the following steps:

- The paper reel indexes by a fixed distance. It has adhesive at the bottom surface.
- The table rises to the required height.
- A hot roller (laminating tool) rolls over it causing it to stick to the previous layer.
- The height is measured and it is passed on to the slicing software.
- The loops of the slice are cut by the laser. It is possible to offset the laser beam by beam radius in such a direction as to compensate for it.
- This is followed by grid cutting around the bounding box of the stock. Note that the grids of all layers coincide.
- Finally, a parting off cut is made.
- The table lowers by a considerable distance so that the cut portion is stripped off from the reel.

* After all layers are made, the built volume is a rectangular block. This is parted off from the table using a thin wire rope.
* The unwanted material inside and surrounding are removed using hand tools. This is called 'decubing'. This operation takes several hours.
* The part is finished and painted as required. It can be given a lacquer coat to prevent it from absorbing moisture.

Advantages

* Only boundaries are to be addressed and not their interiors.
* It employs CO_2 laser which is cheaper. No protective environment is required.
* Paper is very cheap.
* It gives strong wood-like parts. Ideal as patterns for casting

Limitations

* Grid cutting takes much more time than object cutting.
* Decubing also is time-consuming.
* Horizontal surfaces pose problems. Although it is solvable, it has not been done till date.

2.12 Solid Ground Curing (SGC)

Solid Ground Curing process includes three main steps: data preparation, mask generation and model making.

1. **Data Preparation**: In this first step, the CAD model of the job to be prototyped is prepared and the cross-sections are generated digitally and transferred to the mask generator.
2. **Mask Generation**: After data are received, the mask plate is charged through an "imagewise" ionographic process (see item 1, *Fig.2.15*). The charged image is then developed with electrostatic toner.
3. **Model Making**: In this step, a thin layer of photopolymer resin is spread on the work surface (see item 2, *Fig.2.15*). The photo mask from the mask generator is placed in close proximity above the workpiece, and aligned under a collimated UV lamp (item 3). The UV light is turned on for a few

seconds (item 4). The part of the resin layer which is exposed to the UV light through the photo mask is hardened. Note that the layers laid down for exposure to the lamp are actually thicker than the desired thickness. This is to allow for the final milling process. The unsolidified resin is then collected from the workpiece (item 5). This is done by vacuum suction. Following that, melted wax is spread into the cavities created after collecting the liquid resin (item 6). Consequently, the wax in the cavities is cooled to produce a wholly solid layer. Finally, the layer is milled to its exact thickness, producing a flat solid surface ready to receive the next layer (item 7). In the SGC, an additional step (item 8) is provided for final curing of the layer whereby the workpiece travels under a powerful longitudinal UV lamp. The cycle repeats itself until the final layer is completed.

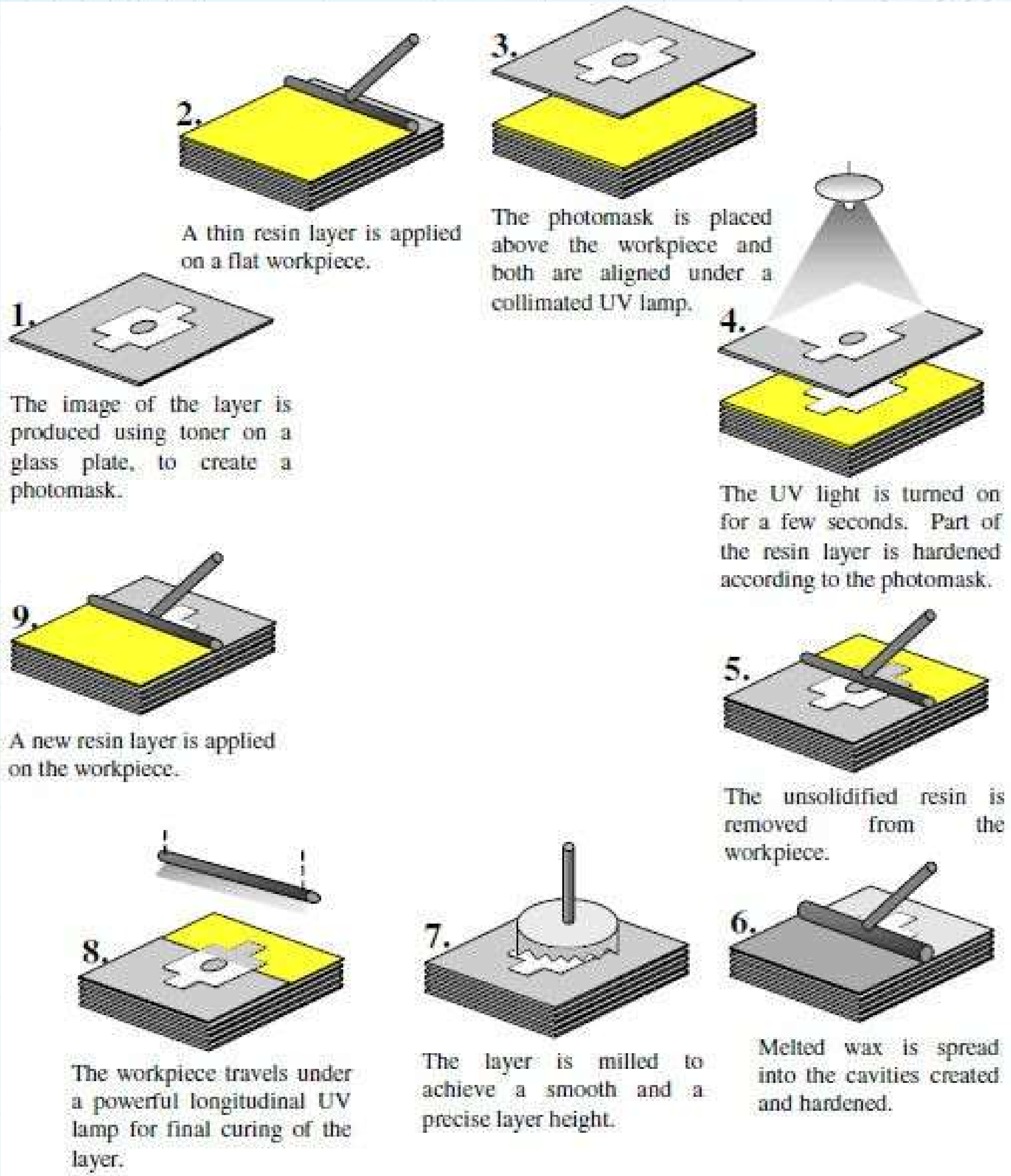

Fig.2.15 – Solid Ground Curing process (Cubital Ltd.)

Applications

The applications of SGC process can be divided into four areas:

i. **General applications.** Conceptual design presentation, design proofing, engineering testing, integration and fitting, functional analysis, exhibitions and pre-production sales, market research, and inter-professional communication.

ii. **Tooling and casting applications.** Investment casting, sand casting, and rapid, tool-free manufacturing of plastic parts.

iii. **Mold and tooling.** Silicon rubber tooling, epoxy tooling, spray metal tooling, acrylic tooling, and plaster mold casting.

iv. **Medical imaging.** Diagnostic, surgical, operation and reconstruction planning and custom prosthesis design.

2.13 Concept Modelers

Principle:

Concept modelers, often called office modelers, are a class of rapid prototyping (RP) system designed specifically to make models quickly and inexpensively, without a great deal of effort. The systems are usually small, inexpensive, quiet, and require very little or no training to operate. For these reasons, the systems are targeted to reside in design office environments, where they can ideally be operated much like a standard printer, only the prints from these systems are in three dimensions.

Thermal Ink jet Printer

Ink jet printing comes from the printer and plotter industry where the technique involves shooting tiny droplets of ink on paper to produce graphic images. RP ink jet techniques utilize ink jet technology to shoot droplets of liquid-to-solid compound and form a layer of an RP model.

The additive fabrication technique of inkjet printing is based on the 2D printer technique of using a jet to deposit tiny drops of ink onto paper. In the additive process, the ink is replaced with thermoplastic and wax materials, which are held in a melted state. When printed, liquid drops of these materials instantly cool and solidify to form a layer of the part. For this reason, the process if often referred to as thermal phase change inkjet printing. Inkjet printing offers the advantages of excellent accuracy and surface finishes. However, the limitations include slow build speeds, few material options, and fragile parts. As a result, the most common application of inkjet printing is prototypes used for form and fit testing. Other applications include jewellery, medical devices, and high-precisions products. Several manufactures have developed different inkjet printing devices that use the basic technique described above. Inkjet printers from Solidscape Inc., such as the Model Maker (MM), use a single jet for the build material and another jet for support material. 3D Systems has implemented their MultiJet Modelling (MJM) technology into their ThermoJet Modeller machines that utilize several hundred nozzles to enable faster build times.

The inkjet printing process, as implemented by Solidscape Inc., begins with the build material (thermoplastic) and support material (wax) being held in a melted state inside two heated reservoirs. These materials are each fed to an inkjet print head which moves in the X-Y plane and shoots tiny droplets to the required locations to form one layer of the part. Both the build material and support material instantly cool and solidify. After a layer has been completed, a milling head moves across the layer to smooth the surface. The particles resulting from this cutting operation are vacuumed away by the particle collector. The elevator then lowers the build platform and part so that the next layer can be built. After this process is repeated for each layer and the part is complete, the part can be removed and the wax support material can be melted away.

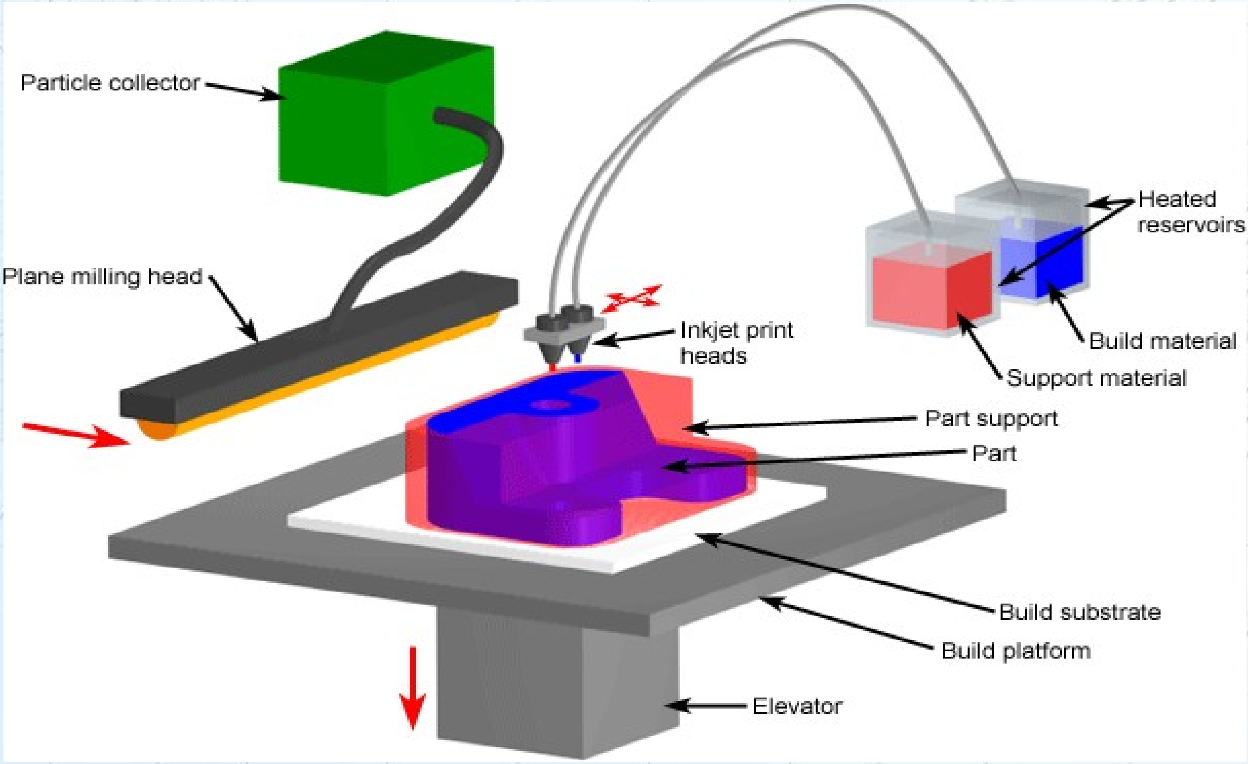

Fig.2.16 – A schematic of Ink jet printer

Common ink jet printing techniques, such as

(a). Sanders Model Maker.

(b). Multi-Jet

Modelling. (c). Z402

Ink Jet System.

(d). Three-Dimensional Printing.

(e). Genisys Xs printer.

(f). Object Quadra systems.

2.13.1 Sander's Model Maker

The Sanders Model Maker (MM) series captures the essence of the ink-jet printing technology, and builds in a layer-by-layer fashion, similar to other rapid prototyping (RP) systems. The MM uses several different types of data file formats but has only one base type for the build and support materials, wax. The MM was developed by Sanders Prototype, Inc. (SPI), a subsidiary of Sanders Design in Wilton, NH, in the early 1990s with the intention of revolutionizing the industry as it pertains t o accuracy and precision.

Model Maker System Hardware

The MM system has evolved through three "models," Model Maker (original model), Model Maker II (MMII, second generation), and recently Rapid Tool Maker (RTM). The original modeller has a build envelope of 7" x 7" and the MMII has an envelope size of 13" x 7", Whereas the RTM has a 12" x 12" working area. While both MMs are desktop models, the RTM is a self-contained unit with an on-board computer. *Fig.2.17* shows an MM unit.

Software:

Both modelers utilize MW (MW) software, manufactured by SPI, to prepare and manipulate the incoming file for use in the MM machine. The software can be operated through a variety of workstations, from UNIX to PC, and the current modeller has an on-board computer that can function alone after it receives the prepared file from a "dummy" PC whose sole purpose is for file slicing and preparation.

Fig.2.17 – Hardware of MM

Build Materials:

Both models use a build and support material to produce a 3-D model. These materials are wax based with the support having a lower melting point than the build. This insures that during postprocessing, the support material will melt away leaving only the part, made of build material. Each material has its own heated reservoir and is very sensitive to contamination, which means handling should not occur.

The Print-head:

The print-head assembly consists of the print-head; print-head cap, purge spout, purge spout cap, cable, and saddle (see *Fig.2.18*). There are two print-heads, one for building the part and the other for generating the necessary support. This support depends on the geometry of the part and can be produced around the entire part or just on certain areas. The jets sit on a carriage that enables them to move in the X and Y direction (left to right), while the stage moves in the Z direction (up and down). There are two processes that enable the materials to be transported to the print-heads.

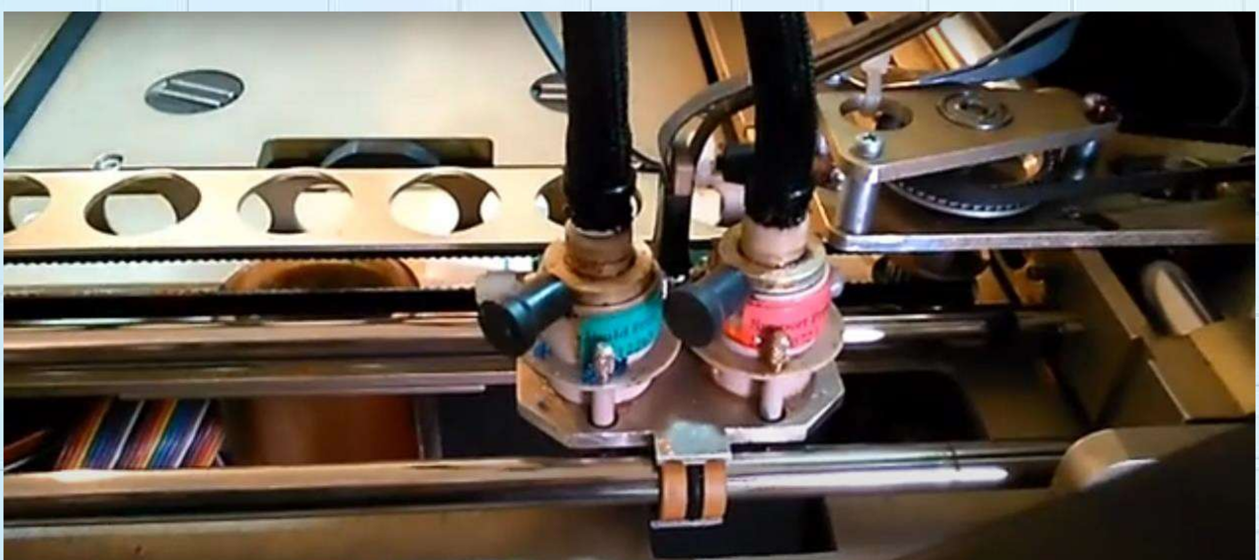

Fig.2.18 – Print-head assembly of the MM

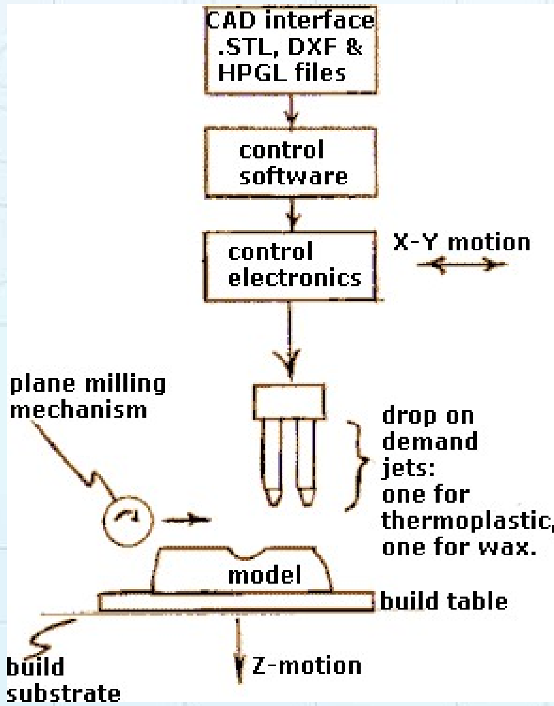

Fig.2.19 – A schematic of MM

1. Material is pumped to the feed lines by compressed air within the reservoir during the purge operation.
2. There is an actual siphon that is conducted from the reservoir to the feed lines, to the printhead during the model build. The feed lines are heated, as are the print-heads. This heating of reservoirs, feed lines, and print heads is necessary to have a continual flow of material.

Model Maker Operation

CAD File Preparation:

Prior to actually building the part, the STL file must be translated into the software language used by the MM. This software is MW and is used for the purpose of preparing and manipulating the file so that the MM can build it.

The file, after being read into MW, produces a picture of the file on screen in the Cartesian coordinate system (-x , -y , and -z). A box appears around this grid with a bar that has many functions that allow the user to put the part in its desired orientation. From this box you can perform slicing functions, zoom functions, layer thickness alterations, part positioning, part sizing and other build parameters. The MW software is very useful and gives the user ultimate control over the end product. *Fig.2.20* shows an STL file as viewed by MW.

Positioning the Model:

There are several factors to consider when positioning the part. Among them are the distance the cutter travels, special features, detailing, opening edges, time to build, and the quality of the model. All of these can be changed as it pertains to the specific characteristics desired for the part. The fundamental rule for positioning is to have the longest length of the part parallel to the cutter.

Configuration Selection:

This is a very important factor prior to building a part. This particular feature is accessed through the **Config** button on the MW window. This notebook contains the database of settings that determine how the model is built. Different parameters can be set with five tabs on the screen. These tabs are: Configuration, Units, Machine, Memory, and Build.

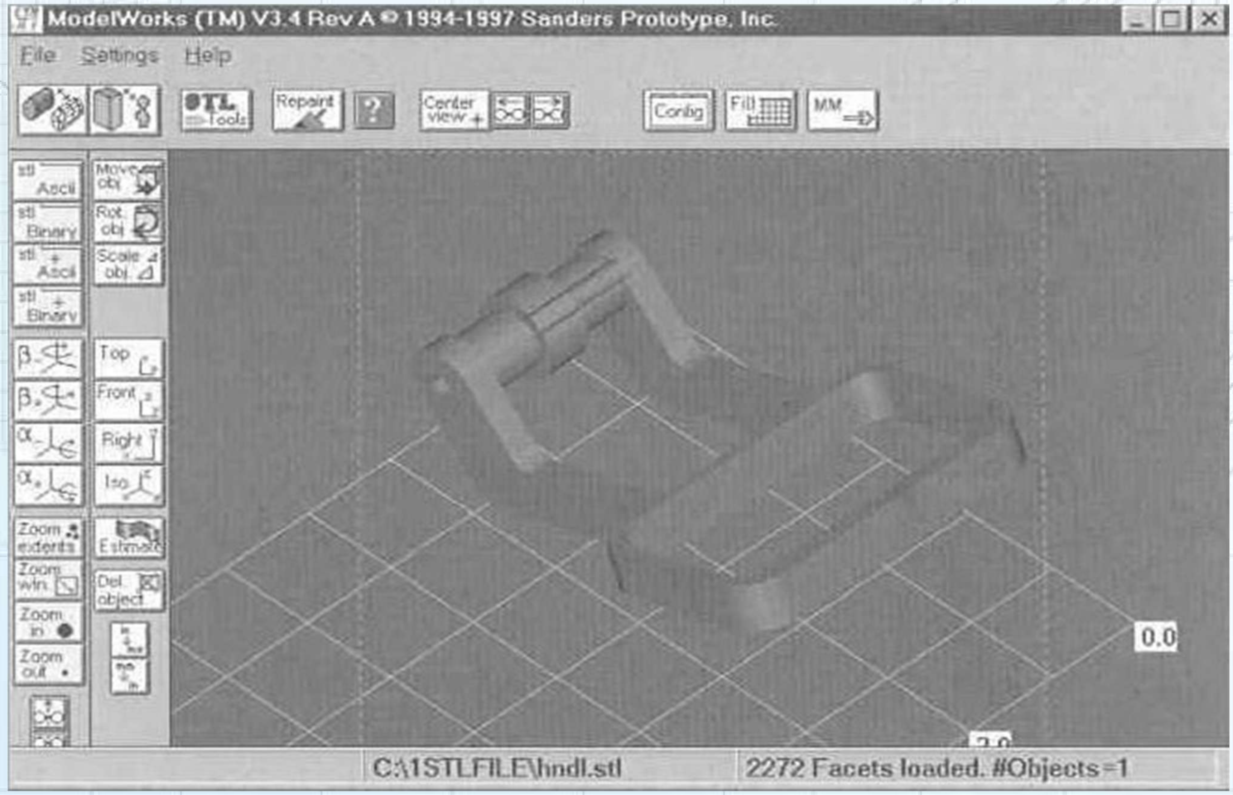

Fig.2.20 – The STL file is viewed with MW before preparation to run

Slicing:

The MM utilizes view as a viewer of the .MM2 and .BIN files generated by MW. This viewer displays slice cross sections and their respective fill patterns. A digital readout at the bottom of the screen gives the ability to extract measurements from this file. This information is helpful in determining the files integrity and getting a view of slice-by-slice formation. This slice-by-slice file is the code the machine will use to generate a layer-bylayer creation of the model. To access this function you must select the **Bview** button from the menu. There are several different functions that you can implement to render the model and file exactly how you desire it to be prior to building. The Navigation buttons allow you to view the model slice by slice or at 10 percent increments, the Automated Control button gives you a real time build slice by slice, the Zoom buttons allow you to adjust the view of the model on the screen, and the Pan buttons allows you to adjust the -x and -y plane views of the model. Together, all of these functions give the modeller complete control over not only how the machine will build the part, but the customization of the part prior to the build.

Building a Part:

Once the part has been delivered to the MMII it is time to prepare the machine for building. Initially, you can check the material reservoirs to determine if you need to add any build or support materials. You can get a graphical representation by selecting <1> on your opening screen. The computer will tell you if additional material is needed and how much to add. Once you have added the material(s), allow 45 minutes for the material to be liquefied in the reservoir before use. But while you are waiting you can check the optical tape receptacle to make sure it is empty and you can mill the substrate. To do so, select **<3>** from the initial screen (Run MM), select <I>, and then <N>, this will allow you to choose the mill command and level your substrate. Mill the original surface (dull finish) of the substrate until it has a clean, bright finish. This ensures that the surface is level. The next and most important step is to check the jet-firing status.

Before each use, perform a manual purge to refill the jet reservoir with material and make sure that the proper amount of air is within the reservoir also. Cut a 3-inch piece of plastic tubing, remove the purge cap, and place the tube on the purge spout. Hold the cylindrical tube over the tube and under <M> choose the respective jet you are purging (build or support). Once the jet has been selected, another menu will appear that will prompt your actions, from this menu, choose the **purge** command. Allow the jet to purge until you get an even flow of material into the tube container and allow it to flow for 2 to 3 seconds, and then press any key to stop the purge. Immediately remove the tube from the spout and reapply the cap. After making sure that the jets are firing properly, go back into new build, select the file you want, and build.

Post-processing:

The post-processing procedure is a process that must be monitored very carefully. When setting your initial temperatures you must be careful because the support material has a lower melting point than the build material. Either you can use a porcelain bowl like container, a hot plate, and a thermometer, or you can purchase a sonicator with heat control and a built-in digital thermometer. If you purchase the latter, remember that the sonication produces its own heat, so additional heat may or may not be necessary depending on the part size. Postprocessing is a hands-on process that involves time and attention. Allow the part to sit in the recommended VSO solvent solution at 35° C for 30-minute increments. Depending on part size you may want to play with the temperature settings and the time you allow it to soak in VSO. You want the support material to be mushy so that you can easily remove it with a tool of your preference (be careful not to destroy part surface). When all the support (red) material has been removed, you may refinish your surface, paint it, or leave it as is. Remember, this process takes time, if you rush it you could sacrifice the integrity of your part.

Advantages and disadvantages

- The power of the MM family of systems lies primarily with the production of small, intricately detailed wax patterns
- The jewellery and medical industries have capitalized on this advantage due to their needs for highly accurate, small parts
- Perhaps the most apparent drawback of these systems are the slow build speed when it comes to fabricating parts larger than a 3- inch working cube.

2.13.2 3-D printers:

Binder printing methods were developed in the early 1990s, primarily at MIT. They developed the 3D printing (3DP) process in which a binder is printed onto a powder bed to form part cross sections. Contrast this concept with SLS, where a laser melts powder particles to define a part cross section. A recoating system similar to SLS machines then deposits another layer of powder, enabling the machine to print binder to define the next cross section. Three-dimensional printing, or 3DP, is an MIT-licensed process, whereby liquid binder is jetted onto a powder media using ink jets to "print" a physical part from computer aided design (CAD) data. Z Corporation (Z Corp) incorporates the 3DP process into the Z402 system. The relatively inexpensive Z402 is directed toward building concept-verification models primarily, as the dimensional accuracy and surface roughness of the parts are less than higher end systems. The initial powder used was starch based and the binder was water based, however now the most commonly used powder is a new gypsum based material with a new binder system as well. Models are built up from bottom to top with layers of the starch powder and binder printed in the shape of the cross sections of the part. The resulting porous model is then infiltrated with wax or another hardener to give the part dexterity. The Z402 is the fastest modeller on the market, with speeds 5 to 10 times faster than other current rapid prototyping (RP) systems. A wide range of polymer, metal, and ceramic materials have been processed.

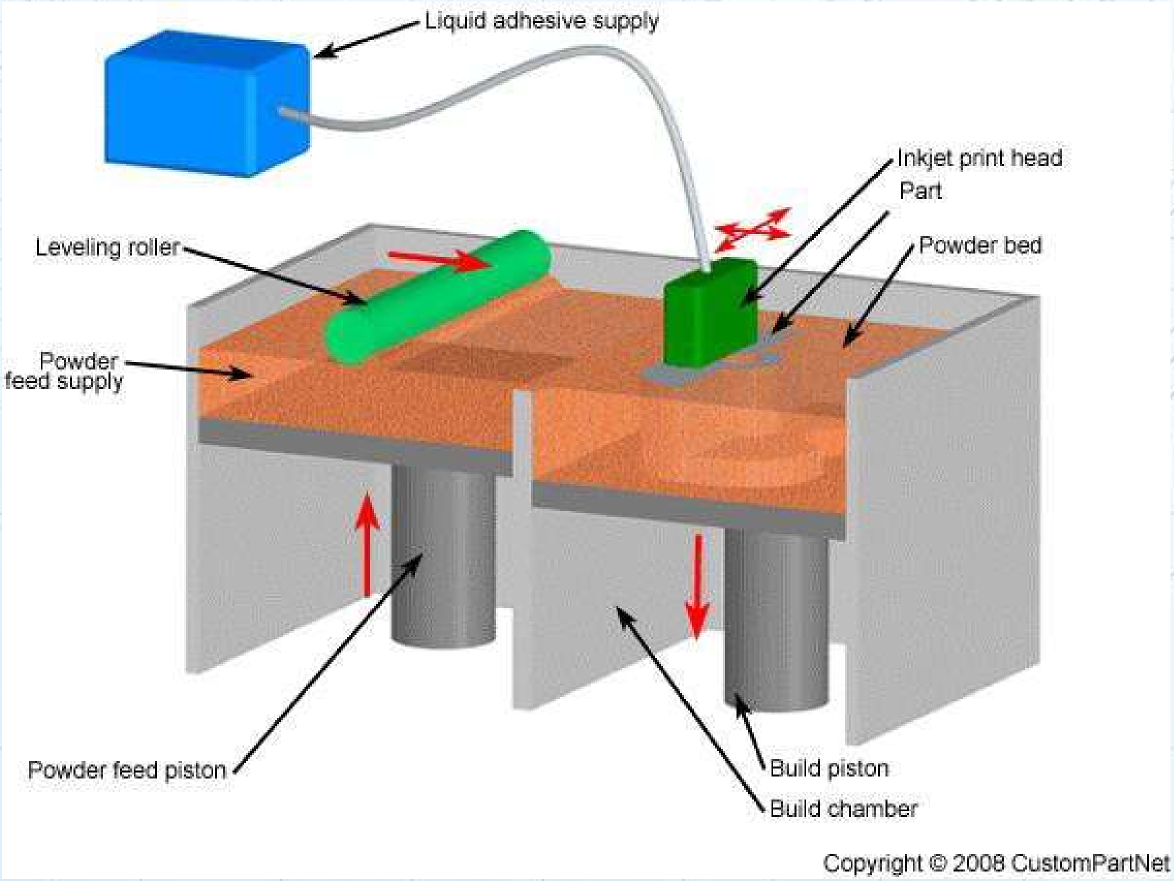

Fig.2.21 – A schematic of 3D printing

Z402 System Hardware:

The Z402 is currently available in only one size, which can build models up to 8" x 11" x 8". The overall size of the modeller is approximately 3' X 4', so it can fit in a fairly confined area. Parts built with the starch material can be hardened to fit the application necessary. Wax infiltration gives the parts some strength but also leaves them usable as investment casting patterns. Stronger infiltrants, such as cyanoacrylate, can be used to provide a durable part that can survive significant handling. Since the starting point of this writing, Z Corp has advanced their 3DP system in several ways. First, they released updated print cartridges (Type 3) that last longer along with stronger infiltrants for durable parts. Secondly, a new material and binder system called ZP100 Microstone was released that provides stronger models directly from the machine with little or no postprocessing or infiltrant. Finally, an automated waxer was released that helps control the wax infiltration process if necessary. The modeler has several important components, including the following:

1. Build and Feed Pistons: These pistons provide the build area and supply material for constructing parts. The build piston lowers as part layers are printed, while the feed piston raises to provide a layer-by-layer supply of new material. This provides the z motion of the part build.

2. Printer Gantry: The printer gantry provides the xy motion of the part building process. It houses the print head, the printer cleaning station, and the wiper/roller for powder landscaping.

3. Powder Overflow System: The powder overflow system is an opening opposite the feed piston where excess powder scraped across the build piston is collected. The excess powder is pulled down into a disposable vacuum bag both by gravity and an onboard vacuum system.

4. Binder Feed/Take-up System: The liquid binder is fed from the container to the printer head by siphon technique, and excess pulled through the printer cleaning station is drained into a separate container. Sensors near the containers warn when the binder is low or the take up is too full. The Z402 is operated through the COM port of a PC Workstation (not included), although the system has an onboard computer that can be used for diagnostics if necessary. The Z Corp slicing software is provided with the purchase of a Z402 system, and is compatible with Windows 98 and Windows NT. Z Corp also sells a postprocessing package necessary for detail finishing and strengthening of the parts produced by 3DP. The package includes a glove box with air compressor and air brushes for excess powder removal, a heating oven to raise the temperature of the parts above that of the wax infiltrant and a wax-dipping unit that melts the wax and provides a dipping area for the parts.

Z402 Operation:

The Z402 has a very user-friendly interface, where very few commands are necessary to build a part. Since the parts are built in a powder bed, no support structures are necessary for overhanging surfaces, unlike most other RP systems.

Software:

The Z402 starts with the standard STL file format, which is imported into the Z Corp software where it is automatically sliced and can be saved as a BLD (build) file. When a file is first imported into the software, it is automatically placed in an orientation with the shortest -z height. This is done as the fastest build capability, like other RP systems, is in the -x, -y direction. The part can be manually reoriented if necessary for best-part appearance.

Multiple STL files can be imported to build various parts at the same time for maximum efficiency. The default slice thickness is 0.008", however the value can be varied to fit the needs for particular parts. Objects can be copied, scaled, rotated or moved for optimum part build. Moving/translating a part can either be done by a simple drag-and-drop method, or else by entering coordinates. Parts can also be justified to either side of the build envelope, be it front, back, left, right, top, or bottom, with a simple menu command. Parts are copied simply by highlighting the part and clicking one copy command. The new part is automatically placed beside the current part if there is room in the build envelope; otherwise it is placed above it. Since the build envelope is a powder bed, three-dimensional nesting can be accomplished so that parts can be built in floating space to make room for others. This 3D nesting capability is only available in a few other RP systems, and provides for a higher throughput of parts to be accomplished. After the STL is imported and placed, a "3D Print" command is issued and the part file is sent to the machine to build. During the build, a progress bar shows the percentage of the part building, as well as the starting time and the estimated completion time. When a build is complete, a dialog box is displayed with the final build time of the part, along with the volume of material used and the average droplet size of the binder used.

- The parts are built in layer-by-layer fashion
- First, blank layers of powder are spread as a starting point for building upon.
- This is called —landscaping
- This landscaping is done manually
- The remaining steps are carried out after this landscaping automatically
- When the first layer of the powder is spread, the liquid binder is called for binder spray
- The binder jet moves as per our virtual design (CAD model)
- After spraying the binder, the next layer of powder is spread and rolled for bonding

- The powder and binder spray depends upon the thickness of the product

The parts that are made using 3D printing, not as strong as SLS products. Because the material is adhesive bonded, where in SLS, the material is taken to fusion bonding.

Postprocessing:

Other than the Z402 system itself, there are several components needed for postprocessing of the part. For a concept model, the starch parts are generally infiltrated with paraffin wax, although more durable materials are available, from plastics to cyanoacrylate. Before infiltration, starch parts are fragile and must be handled with care. The following are the postprocessing steps for a part to be infiltrated with wax, with a total process time of about 15 to 20 minutes.

1. Powder Removal: After the parts are taken from the machine, the excess powder must be removed. With the system comes a small glove box with an airbrush system inside. The airbrush is used to easily and gently blow the powder off the part, and a vacuum cleaner is hooked to the glove box to remove the powder as it is blown from the part. (5 Minutes)

2. Heat for Infiltration: Once the powder is removed from the part surfaces, the part is placed in a small oven and heated to a temperature just above that of the infiltrant wax, to provide a wicking characteristic as opposed to coating. The part temperature for paraffin infiltrant is approximately 200°F. (10 Minutes).

3. Infiltration: Immediately after the part is heated, it is dipped for a few seconds into a vat of molten wax, then removed and placed on a sheet to dry. After drying the part is complete. (5 Minutes)

The actual postprocessing time will depend on the complexity of the part, the skill of the user, and the infiltrant used. Nonetheless, it is still minimal compared to some other RP processes.

Typical Uses of Z402 Parts

Parts built with the Z402 system are directly intended for use as conceptverification models in a design environment. The nontoxic materials allow for the models to be safely handled in meetings or the office, directly after fabrication. Another application that is beginning to be explored, not unlike other RP systems, is the use of Z402 parts for investment or sandcast patterns. The starchbased material burns out of an investment shell readily, therefore providing a quick way to produce metal hardware for testing or analysis.

Advantages and Disadvantages of the Z402

Ultimately, the speed is the most desirable trait of the Z402. With an average build time of one vertical inch per hour, even a part several inches tall can be built within a normal work day. This is extremely advantageous to any company where time is a factor in sales or production. The key disadvantages of the system include rough part surfaces, which can be remedied with sanding, and the cleanliness problems faced when dealing with any system that uses a powder as a build material or operating medium. Also, the ink-jet cartridges must be replaced quite frequently, on the order of every 100 hours of operation, so users must understand that the jets are expendable items just as the build powder itself. Finally, these concept models aren't fabricated to high dimensional tolerances, which may hinder the building of complex assembly prototypes.

2.13.3 Genisys Xs printer HP system

The Genisys (and Genisys Xs) system, produced by Stratasys, Inc. is an office - friendly modelling system that builds parts with a durable polyester material. The current line of Genisys systems are small, compact table-top rapid prototyping (RP) machines that deliver singlematerial capability, and interoffice network queues for operation much like a printer.

History of the System

Not unlike most newly developed technologies, the original Genisys machines had small quirks and technicalities that prevented it from really being a true "trouble free" office modeller. However, after analyzing and working with customers, most of the systems were recalled and refurbished to correct the problems. The new line of Genisys, the Xs, apparently has printer-like reliability and operation, providing concept-modelling capability to the office environment as intended.

System Operation

Software

The software of the Genisys systems, which is compatible on both Unix and NT platforms, is designed for ease of operation. With simple point-and-click partbuilding features, the software automatically places, slices, generates supports, and then downloads the part file to the network queue to be fabricated. Parts can be set to be scaled automatically as well, although there is a manual scaling feature. Multiple parts may be nested in the -x, -y plane, again with single-click operability.

Build Material

The current build material is quoted as a "durable polyester". Since the systems have only one extrusion tip, the support structures are built of the same material, requiring mechanical removal upon completion of the part.

Hardware:

The Genisys has a maximum build capacity of 12" X 8" x 8", whereas the entire system occupies a space of only 36" x 32" x 29". The unit weighs in at about 210 pounds and can operate on standard house current of 110 to 120 Volts AC. The polyester material comes stock in the form of wafers, which are loaded into a bank of cartridges within the machine. One wafer is loaded into the deposition head, where it is melted and deposited in thin layers through a single extrusion tip while tracing the cross section of the part being built. Once the wafer in the head is spent, it is replaced by another automatically and the build resumes. The build chamber is operated at ambient temperature, and fabricated parts can maintain dimensional accuracy in the range of +0.013 inches.

Fig.2.22 – Genisys Xs printer HP system

Typical Uses of Genisys Parts

The intended application of the Genisys system's product was mainly concept modelling and verification. However, as with all RP devices, various users have progressed the use of Genisys models into analysis, direct use, even low-impact wind-tunnel modelling. The material is said to be suitable for painting, drilling, and bonding to create the necessary appearance for an application.

Advantages and Disadvantages of Genisys

The advantages of the Genisys system include the ease of use and the network operability. Since the preprocessing is kept to a minimum, and the systems can be networked much like printers, the Genisys lends itself to the office modelling environment. Perhaps the major disadvantage of the system would be its single- material capacity, which results in more difficult support removal on complex parts. This situation may well be addressed in the future, similar to what was done in the progression of its sister technology of fused deposition modelling, however the vendor has no plans released at the time of this writing.

2.13.4 Object Quadra systems

The Quadra process is based on state-of-the-art ink-jet printing technology. The printer, which uses 1536 nozzles, jets a proprietary photopolymer developed inhouse by Objet. Because it requires no postcure or postprocessing, Quadra touts the fastest start-to-finish process of any (RP) machine currently on the market. Objet will initially offer one grade of material with properties similar to multipurpose resins currently offered with competitive RP systems. Additional materials with varying properties are under development. Material is delivered by a sealed cartridge that is easily installed and replaced. Jetting of different resins, once they become available, will not require costly investments in materials or hardware upgrades.

A new cartridge is dropped into place without any complicated procedures or specially trained staff. Quadra deposits a second material that is jetted to support models containing complicated geometry, such as overhangs and undercuts. The support material is easily removed by hand after building the model. The support material separates easily from the model body without leaving any contact points or blemishes to the model. No special staff or training are required. Furthermore, models built on the system do not require sanding or smoothing where the supports are attached.

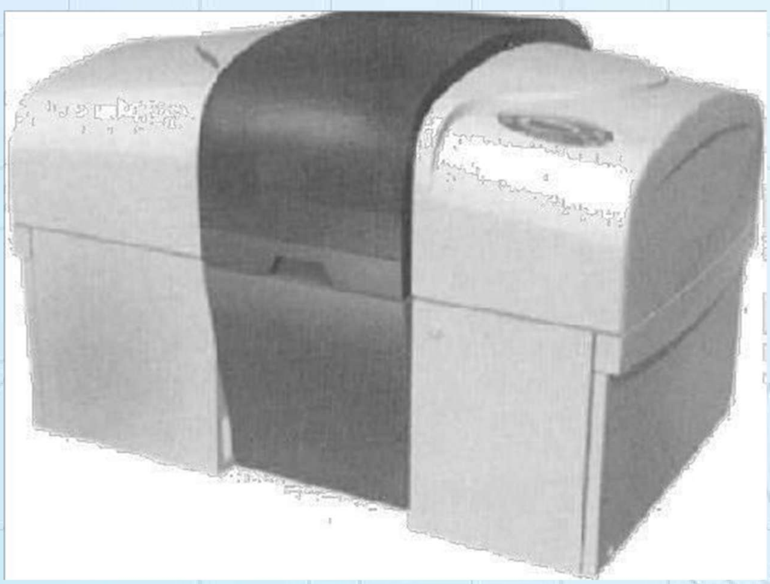

Fig.2.23 – A Quadra system from Object

Object Quadra offers significant advantages over previous technologies in the field. The material properties of items printed on Quadra are unmatched by machines in its class and price category, and are equalled only by industrial systems that cost an order of magnitude more. The Quadra prints in a resolution of 600 dpi, with a layer thickness of 20 microns, and builds parts up to a maximum size of 11" x 12" x 8". The introduction of Quadra marks the start of a revolution in the area of three-dimensional imaging. An intuitive user interface aids users in setting up the build, scaling, and positioning single and multiple models. Maintenance costs for Quadra are expected to be low. The UV lamps are a standard off-the-shelf item, priced below $75 each, with a life of 1,000 hours. Users can easily replace the lamps themselves.

Fig.2.24 – Parts from the Quadra

2.14 References

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