ME 18002

3D Printing
&
Design

SYLLABUS

UNIT I	Introduction to Additive Manufacturing
UNIT II	Additive Manufacturing Processes
UNIT III	Design for Additive Manufacturing
UNIT IV	Post Processing
UNIT V	Applications of Additive Manufacturing

Books

- Rapid Prototyping: Principles & Applications, Chua C.K, Leong K.F & Lim C.S (Hard copy & E-Book)
- Rapid Prototyping, Gebhardt A (E-Book)
- Rapid Prototyping & Engineering Applications : A tool box for prototype development, Liou L.W. & Liou F.W (Hard Copy & E-Book)
- Rapid Prototyping : Theory & Practice, Kamrani A.K. & Nasr E.A (Hard copy & E-Book)
- Rapid Tooling: Technologies & Industrial Applications, Hilton P.D & Jacobs P.F (E-Book)
- Rapid Manufacturing, D.T. Pham and S.S. Dimov, (E-Book)

Introduction – Types of Mfg.

- Metal Forming
  - Bending, Spinning, Drawing, and Stretching
- Metal Casting
- Metal Removal
  - Machining
- Metal Joining
  - Welding, Brazing
- Additive Manufacturing / Rapid Prototyping / 3D Printing / Rapid Manufacturing

Introduction – Prototyping

- What is a prototype?
  - A prototype is an early sample, model, or release of a product built to test a concept or process or to act as a thing to be replicated or learned from
  - Prototyping serves to provide specifications for a real, working system rather than a theoretical one

Introduction – Types of Prototype

- A Proof-of-Principle Prototype serves to verify some key functional aspects of the intended design, but usually does not have all the functionality of the final product.
- A Working Prototype represents all or nearly all of the functionality of the final product.
- A Visual Prototype represents the size and appearance, but not the functionality, of the intended design.
- A Form Study Prototype is a preliminary type of visual prototype in which the geometric features of a design are emphasized, with less concern for color, texture, or other aspects of the final appearance.

Introduction – Types of Prototype

- A User Experience Prototype represents enough of the appearance and function of the product that it can be used for user research.
- A Functional Prototype captures both function and appearance of the intended design, though it may be created with different techniques and even different scale from final design.
- A Paper Prototype is a printed or hand-drawn representation of the user interface of a software product. Such prototypes are commonly used for early testing of a software design, and can be part of a software walkthrough to confirm design decisions before more costly levels of design effort are expended.

Unit – I : Introduction

- Introduction to AM
- AM evolution
- Distinction between AM & CNC machining,
- Advantages of AM
- AM process chain: Conceptualization, CAD, conversion to STL, Transfer to AM
- STL file manipulation
- Machine setup, build , removal and clean up,
- Post processing.

Overview

- Prototyping
- Rapid Prototyping
- Rapid Tooling
- Additive Manufacturing / 3D Printing
- Rapid Manufacturing

Additive Manufacturing (Rapid Prototyping)

- Building 3D parts directly from their computer models without going through the mfg. steps such as process planning and tool mfg.

Need for RP (AM)

- Introducing new products at ever increasing rates is crucial for remaining successful in a competitive global economy

- Decreasing product development cycle times and increasing product complexity require new ways to realize innovative ideas

Technology for AM

Layered Manufacturing

Or

Solid Freeform Fabrication (SFF)

History

- 1890 – Blanther – layered method for making a mould for topographical relief maps

Summit Terragraphics Inc.

Raised-Relief Map of Kenai Fjords National Park, Alaska
Created from 2D Brochure Map for the National Park Service

History

- 1940 – Perera – Cardboard sheets – stacking
- 1985 – Commercial development started
- 1988 – First commercial RP machine – 3D Systems

Impact of RP & T on Product Development

- Design cost – 70%

  i.e. once the design is released 70% of the cost of the product is fixed.

Design - 70%
Material - 20%
Labour - 5%
Overheads - 5%

Impact of change on cost

- Concept stage - X
- Design Stage - 10X
- Tooling Stage - 100X
- Testing Stage - 1000X
- Post Release - 10000X

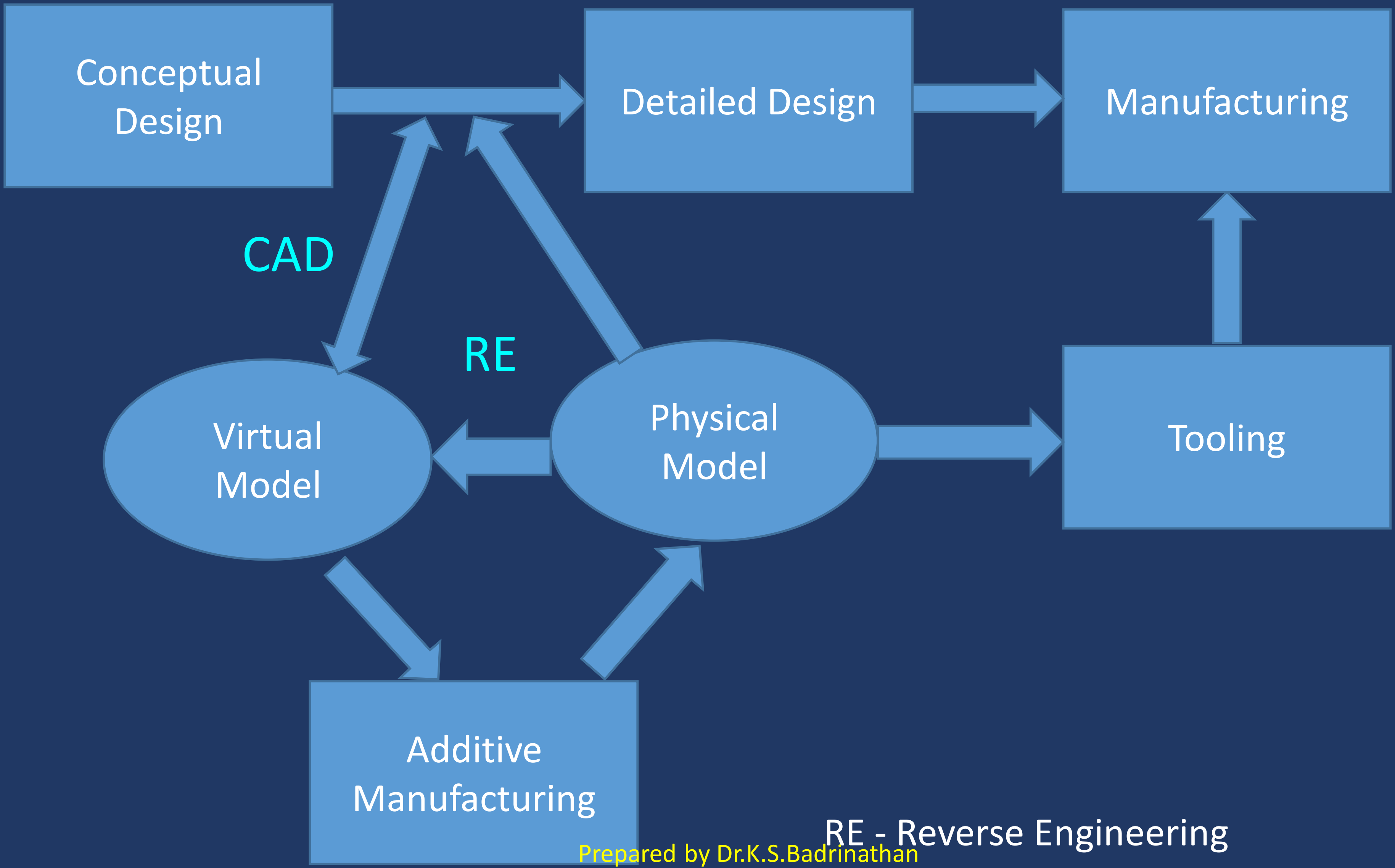
Benefits

- Investments in design yields the highest returns for manufacturing companies.
- Improves almost all sensible aspects of products & makes it more competitive; comparatively risk-free and inexpensive
- It contributes in 3 main areas to improve competitiveness.
  - Cost : reduce mfg. cost & recurring cost
  - Acceptability: improves product uniqueness, appearance, user friendliness, reliability & safety
  - Service: improved packaging ensures safe delivery and reduce repair & maintenance.

Benefits of Prototype

- Working prototypes play a vital role for proving the functions of the new technology
- Plastic Prototype : ‘one-go’ product ; production moulds for plastics are very expensive & requires considerable fabrication time.

Role of AM in Product Dev.



RE - Reverse Engineering

Advantages of 3D Printing

- Lower cost of prototyping
- Shorter lead times
- Improved total product quality

Attributes of AM

- Can build arbitrarily complex 3D geometries
- Process planning is automatic, based on CAD model
- Use a generic fabrication machine i.e. do not require part-specific fixturing & tooling
- Requires minimal or no human intervention to operate

Benefits of AM

To the product designer

- Increase product complexity with little effect on lead time and cost
- Optimize the part design to meet customer requirements
- Improved design creativity
- Valuable feed back on the design can be obtained from various sources

Benefits of AM

To the Manufacturer

- Early realization of profit
- Reduced cost due to reduction in wastage & scrap
- Reduced labour content
- Design errors like too thin walls, misaligned apertures can be identified and solved at early stage
- Tooling can be done only when the concept is refined

Benefits of AM

To the Marketer

- Reduced time-to-market
- Reduced risk of product failure
- Make products meeting customer requirements
- Test-marketing of new products is possible
- Limited edition of variety of conceptual prototypes can be launched followed by mass production

Benefits of AM

To the customer

- Gets products which meet more closely the individual needs and wants

Basic Concept

CREATING THE 3D CAD MODEL OF THE DESIGN

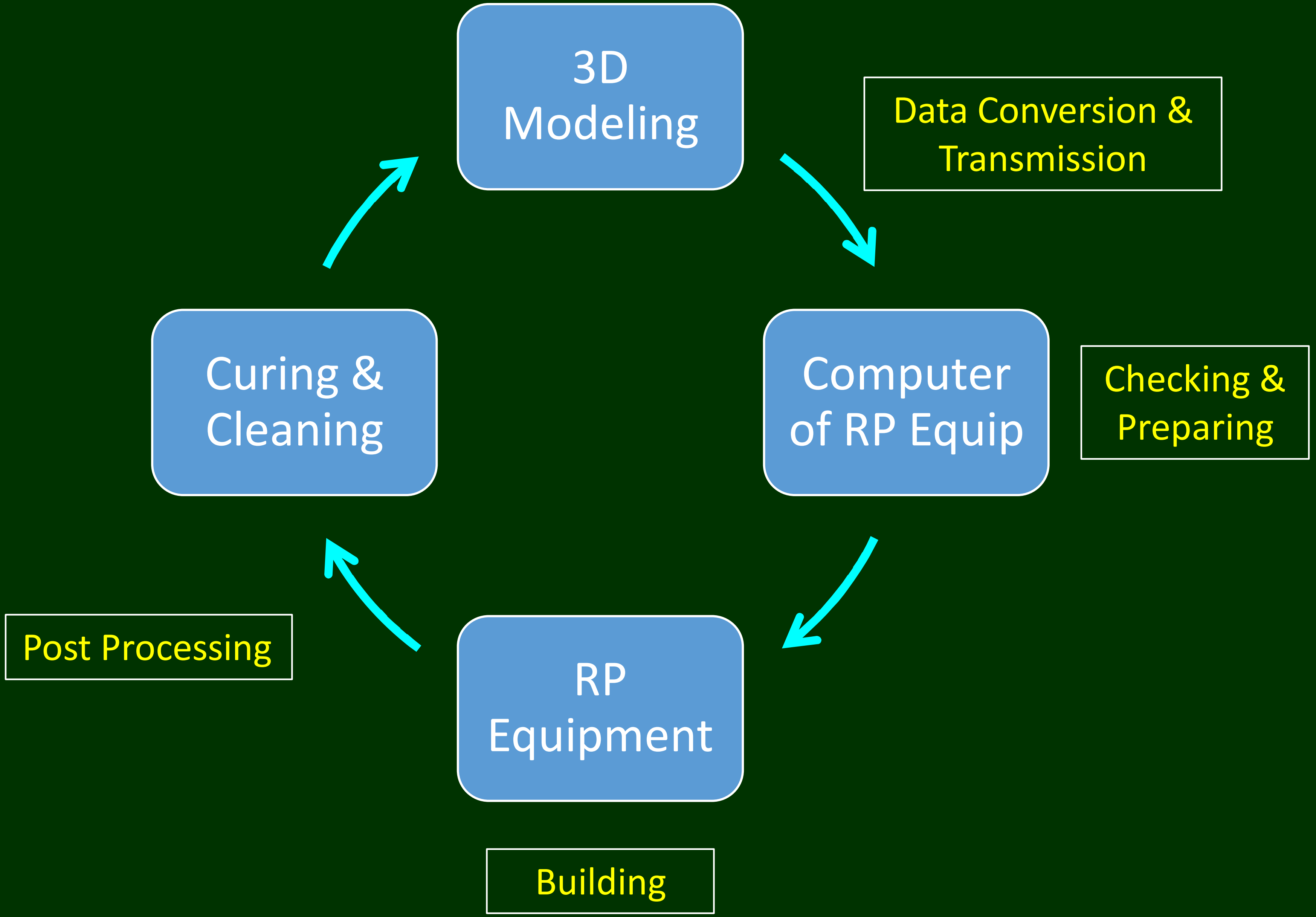
CONVERTING THE CAD MODEL INTO STL FORMAT

SLICING THE STL FILE INTO THIN LAYERS

CONSTRUCTING THE MODEL ONE LAYER ATOP ANOTHER

CLEANING AND FINISHING THE MODEL

AM Process Chain



3D Modeling

Data Conversion & Transmission

Computer of RP Equip

Checking & Preparing

RP Equipment

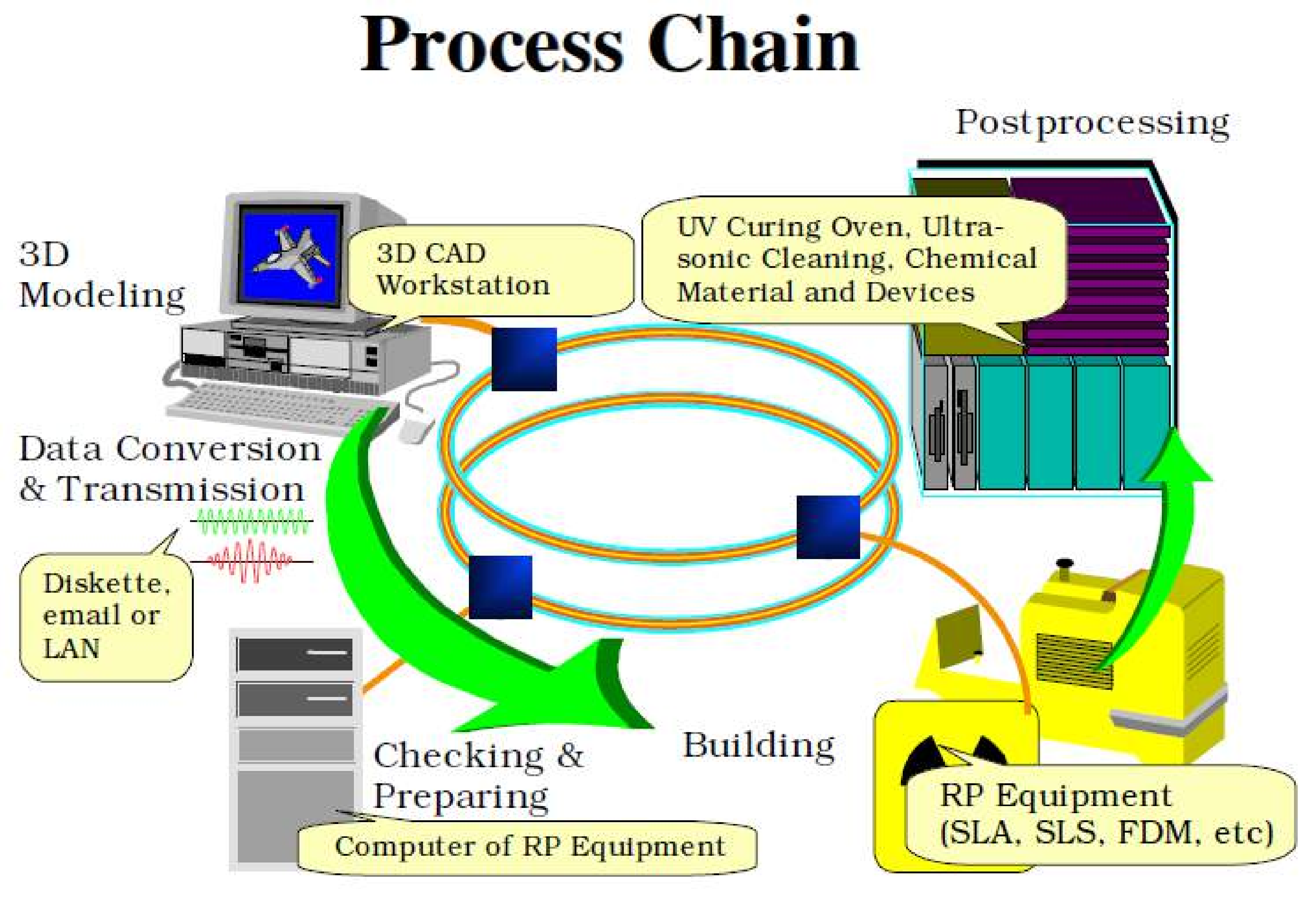
Building

Curing & Cleaning

Post Processing

Prepared by Dr.K.S.Badrinathan

AM Process Chain



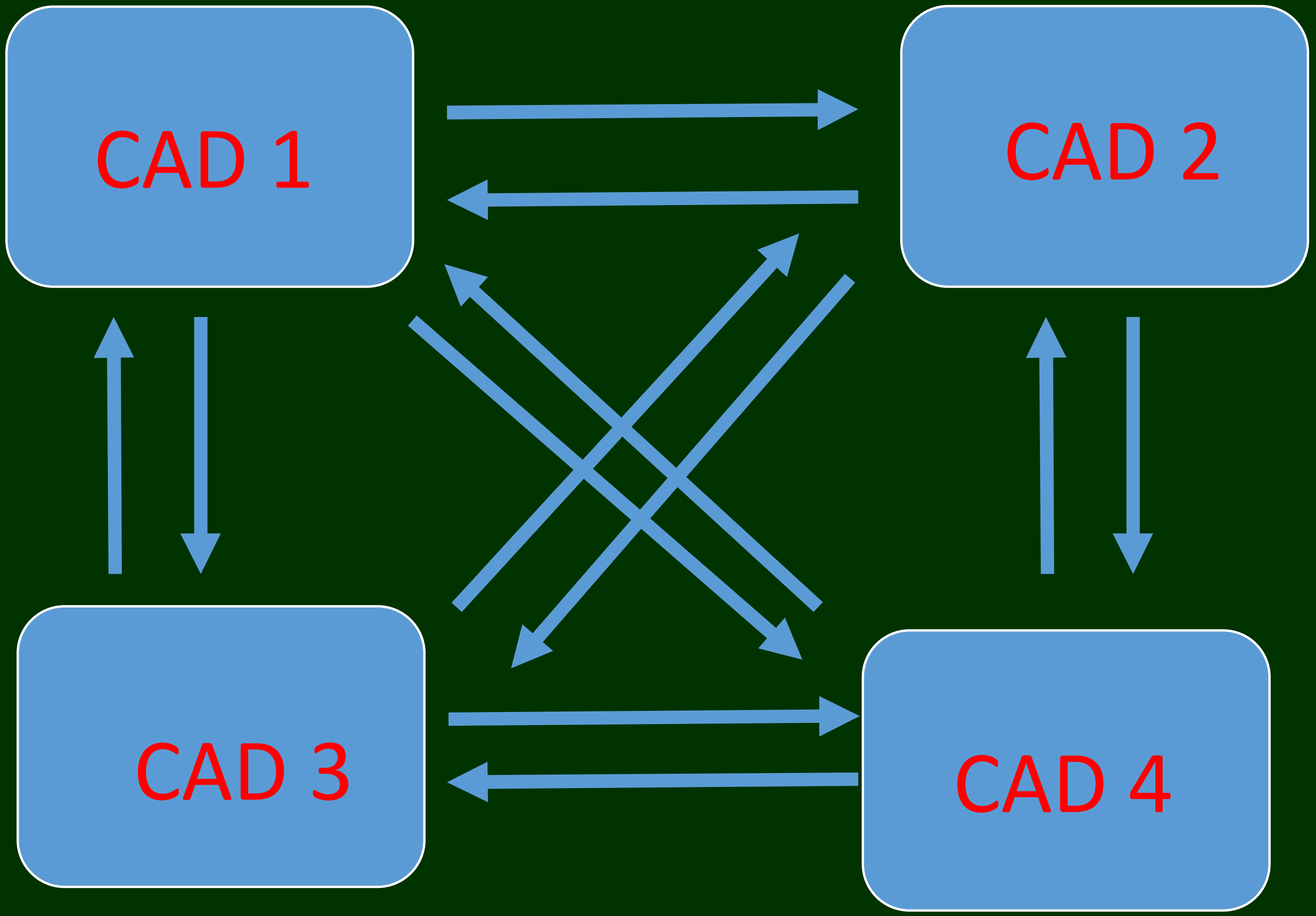
1. 3D Modelling

- Considerations that must be taken into account
  - orientation of part
  - need for supports
  - difficult-to-build part structure such as thin walls
  - small slots
  - holes
  - overhanging elements.

Data Conversion

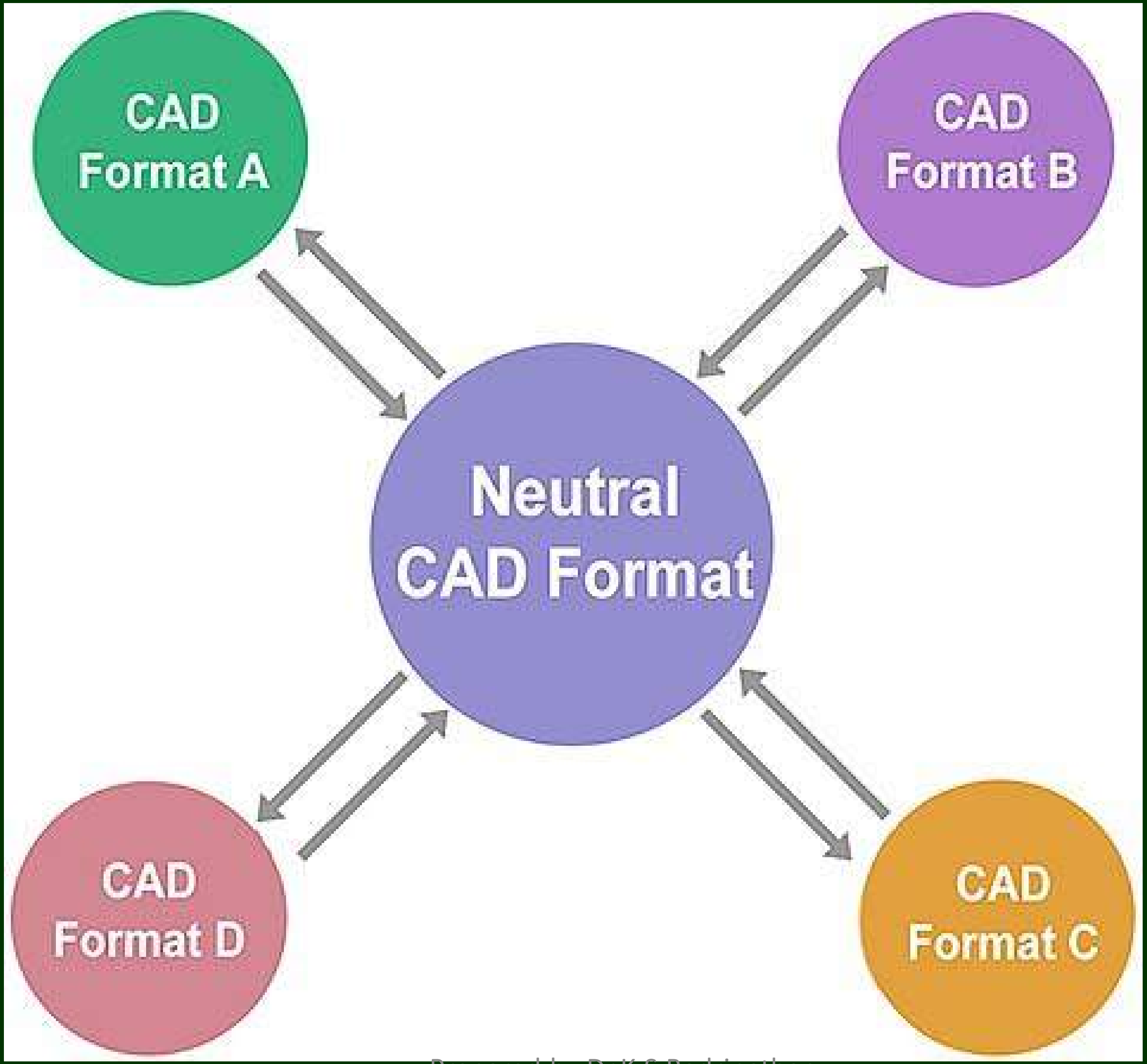
- Direct Translation
  - Read in native format
- Indirect Translation
  - Read in neutral format
    - DXF (Data eXchange Format)
    - IGES (Initial Graphics Exchange Specification)
    - STEP (STandard for Exchange of Product Data)
    - PDES (Product Data Exchange using STEP)

CAD Direct Translation



Prepared by Dr.K.S.Badrinathan

CAD Indirect Translation



3D Printed House

3D Printed House

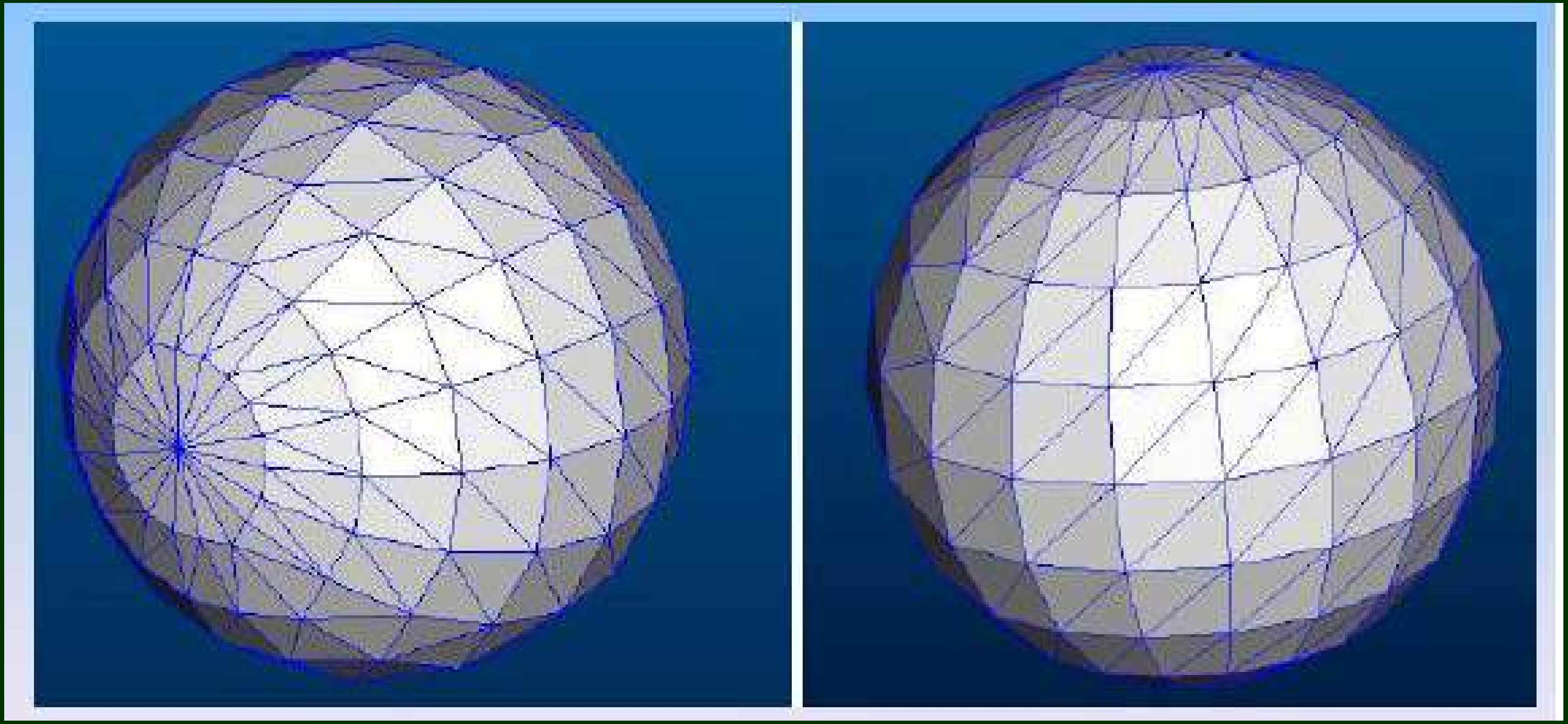
- PassivDom - With the power of their 3D printing robot, they can create a 410 square foot model featuring walls, a roof, and a floor in right under eight hours.
- After the home is created, manpower is needed to complete the wiring of the home.
- $64,000 (Rs.40 lacs)
- Easily transportable

Source: www.interestingengineering.com

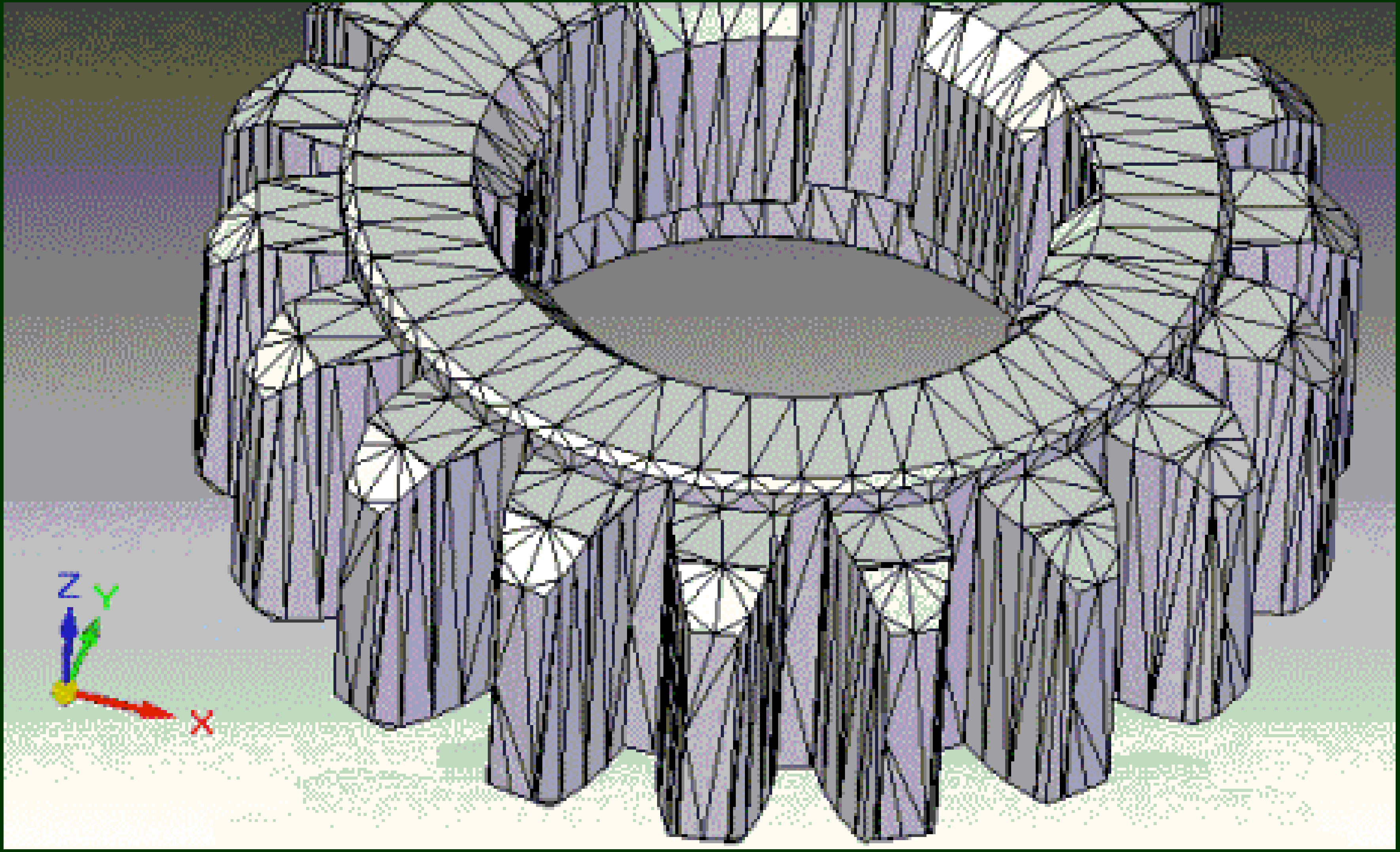
2. Data Conversion & Transmission

- 3D model is converted into STL file format
- ‘3D Systems’ pioneers the **ST**ereo**L**ithography system
- STL approximates the surfaces of the model using tiny triangular facets.
- Small facets → high quality surface
- supports are converted to a separate STL file

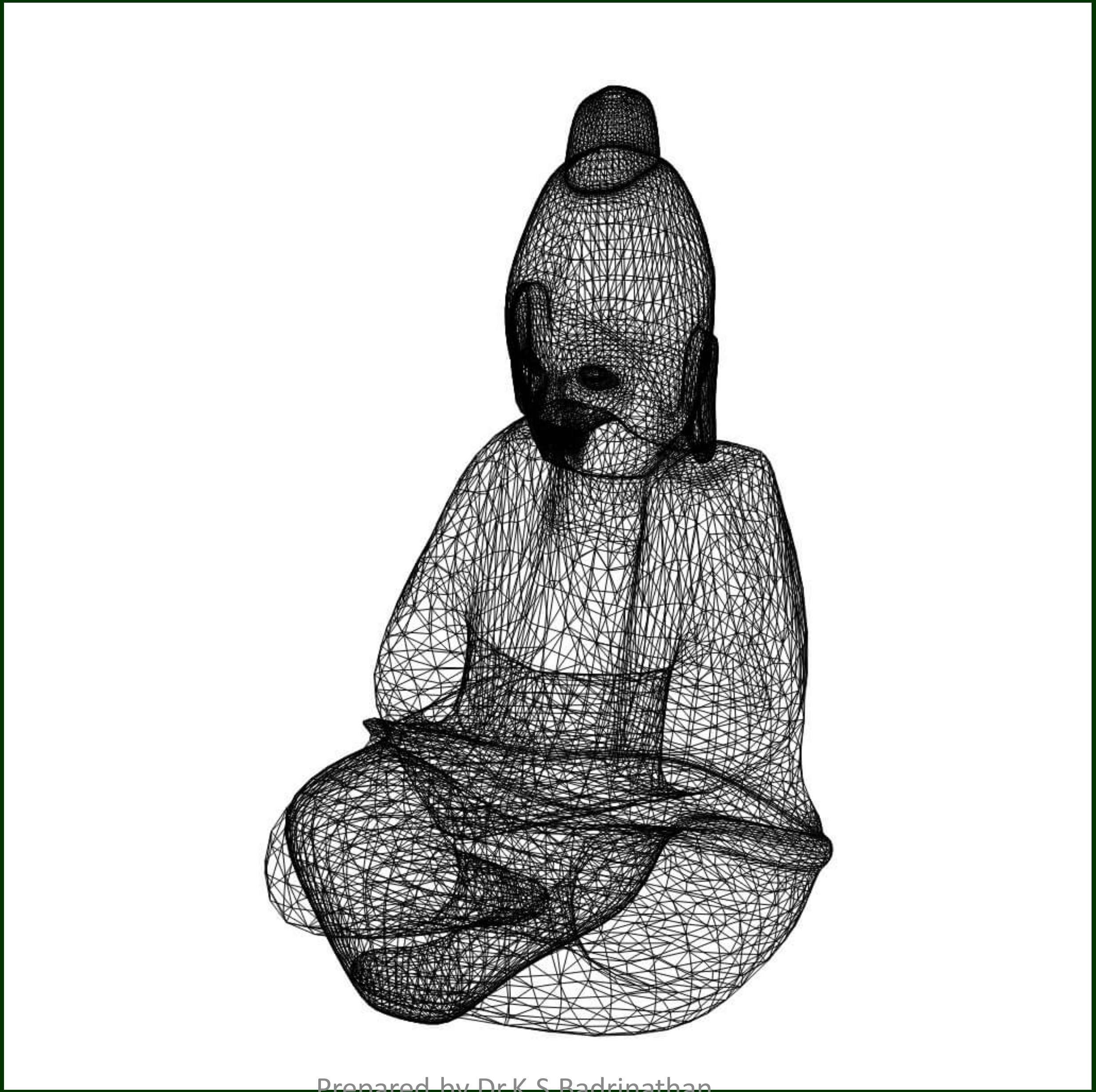
Triangular Facets



Triangular Facets



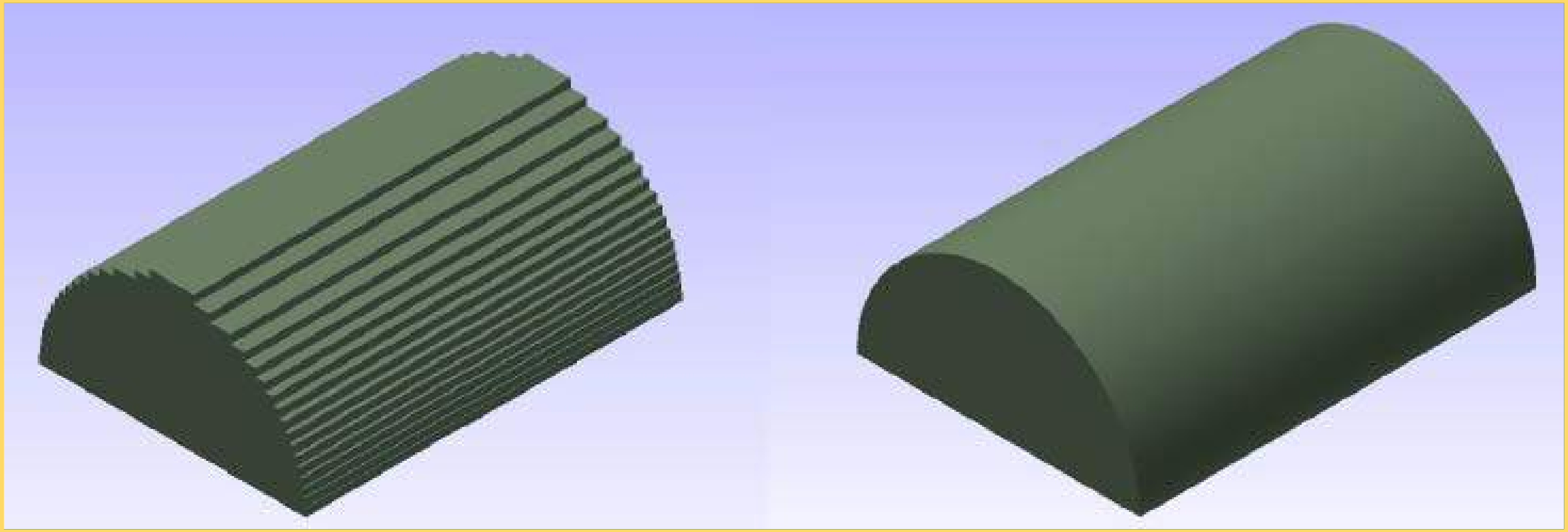
Triangular Facets



3. Checking & Preparing

- STL files may be faulty
- Problems - generation of unwanted shell-punctures (holes, gaps, cracks, etc)
- corrected manually assisted by specialized software such as MAGICS
- AM system's computer slices the model into cross-sections

Slicing



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Slicing

Machine Setup

- arrangement with other parts,
- necessary support
- structures and slice parameters
- Layer thickness
- 3D Systems - Partman Program- setting parameters -SLA

4. Building

- Fully automated
- Superficial monitoring –
    - running out of material
    - power or
    - software glitches

5. Post Processing

- Cleaning - removal of excess parts (SLA)
- Curing : UV treatment etc.
- Sanding & Painting : improve the surface finish or aesthetic appearance
- Additional machining : drilling, tapping and milling to add necessary features to the parts

CNC-vs-AM

CNC	AM
subtractive	additive
hard, relatively brittle materials like steels and other metal alloys	polymeric materials, waxes, and paper laminates
MRR is faster than AM machines for a similar volume of material	Slower for the same volume
repositioning or relocation of parts within one machine or more than one machine	Single stage building
higher geometric complexity is not possible	possible
program involves, tool selection, machine speed settings, approach position and angle, etc	Programming is not very critical

END of Unit - 1

ME 18002
3D Printing & Design

UNIT – II

AM PROCESSES

Unit-II Syllabus

- Liquid polymer system
- Discrete particle system
- Molten material systems
- Solid sheet system

Classification of AM

Based on the initial form of material

- Liquid Based Processes
- Molten Material systems
- Solid Based Processes
- Discrete particle system (powder)

Liquid-Based Process

- Initially the material is in liquid state.
- Using a process called ‘Curing’ the liquid is converted into solid state
- Processes:
  - Stereolithography (SLA)
  - Solid Ground Curing (SGC)

STEREOLITHOGRAPHY APPARATUS (SLA)

- 3D Systems - founded in 1986
- SLA - pioneer -first commercial system marketed in 1988
- 40 United States patents
- 20 International patents

SLA Principle

- Photo-curable liquid resin cures when exposed to a laser beam (photo polymerization process) which scans across the surface of the resin.

- The building is done layer by layer, each layer being scanned by the optical scanning system and controlled by an elevation mechanism which lowers at the completion of each layer.

Photopolymers

- Liquid photopolymers are solidified by exposure to:
    - Electro-magnetic radiation
    - Gamma rays
    - X-rays
    - UV (UltraViolet)
    - Electron-beam (EB)

Photopolymers

- Photopolymers in SLA machines are curable in the UV range.

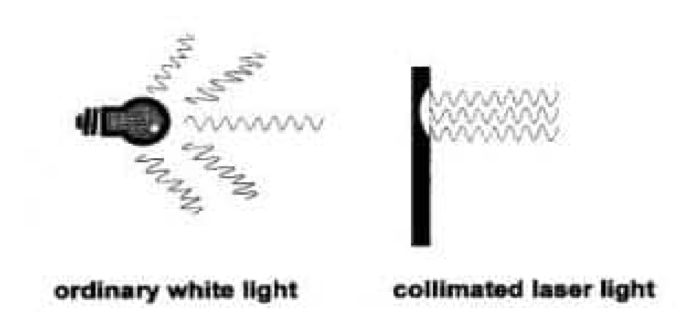
- UV-curable photopolymers are resins which are formulated from photo initiators and reactive liquid monomers.

Photopolymerization

- Polymerization is the process of linking small molecules (known as monomers) into chain-like larger molecules (known as polymers)

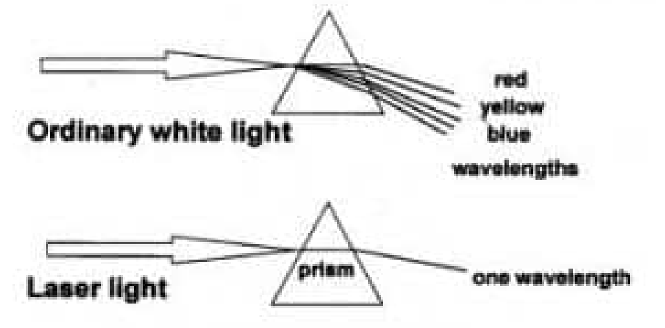
Properties of Laser

- Collimation/Non-Divergence

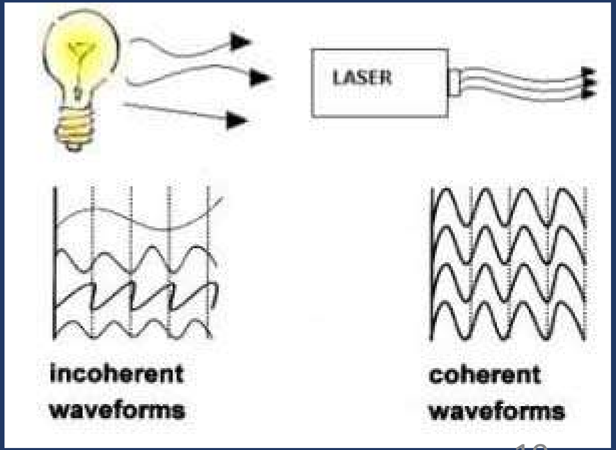


- Monochromatic -

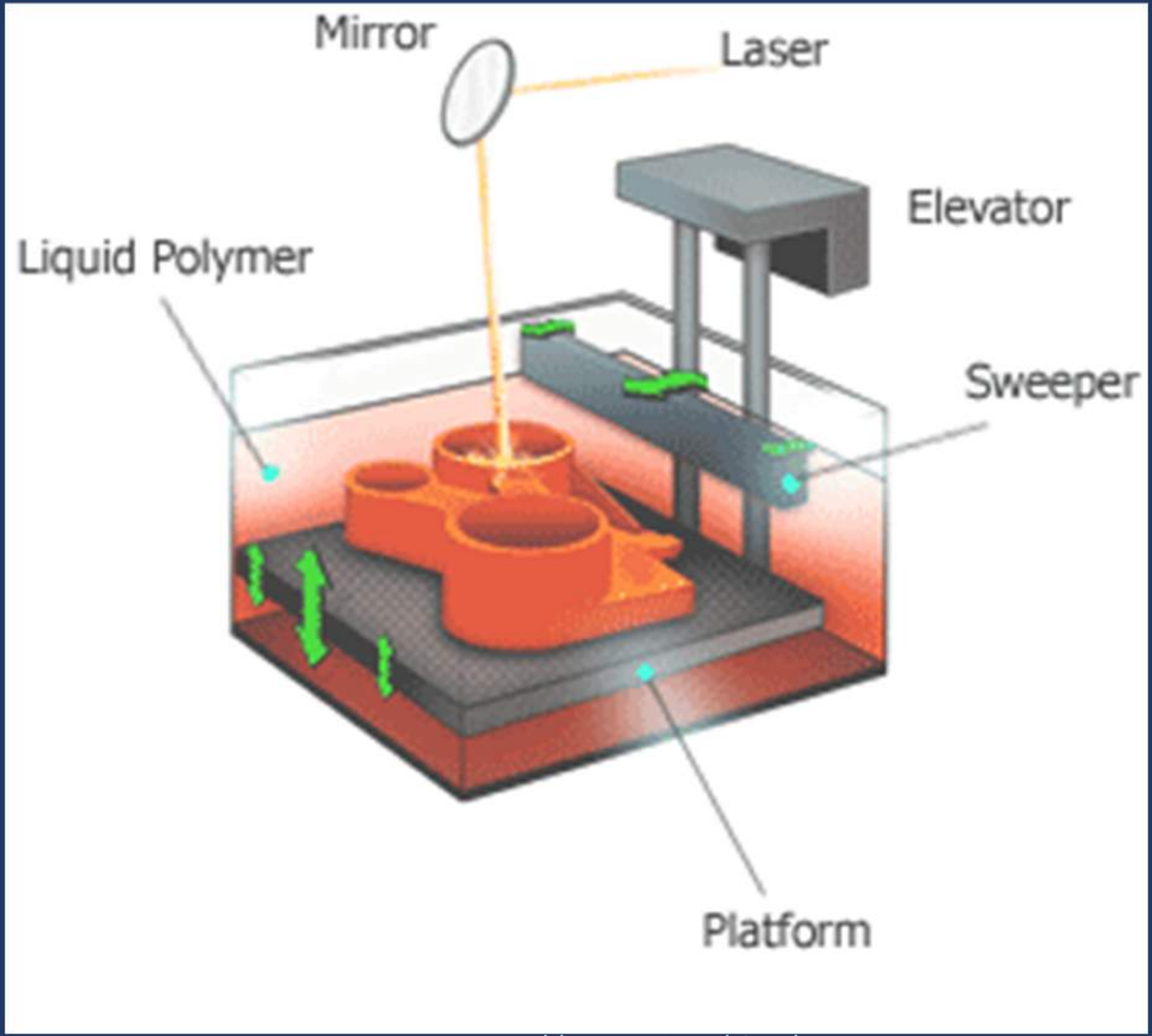
  single (wavelength) color



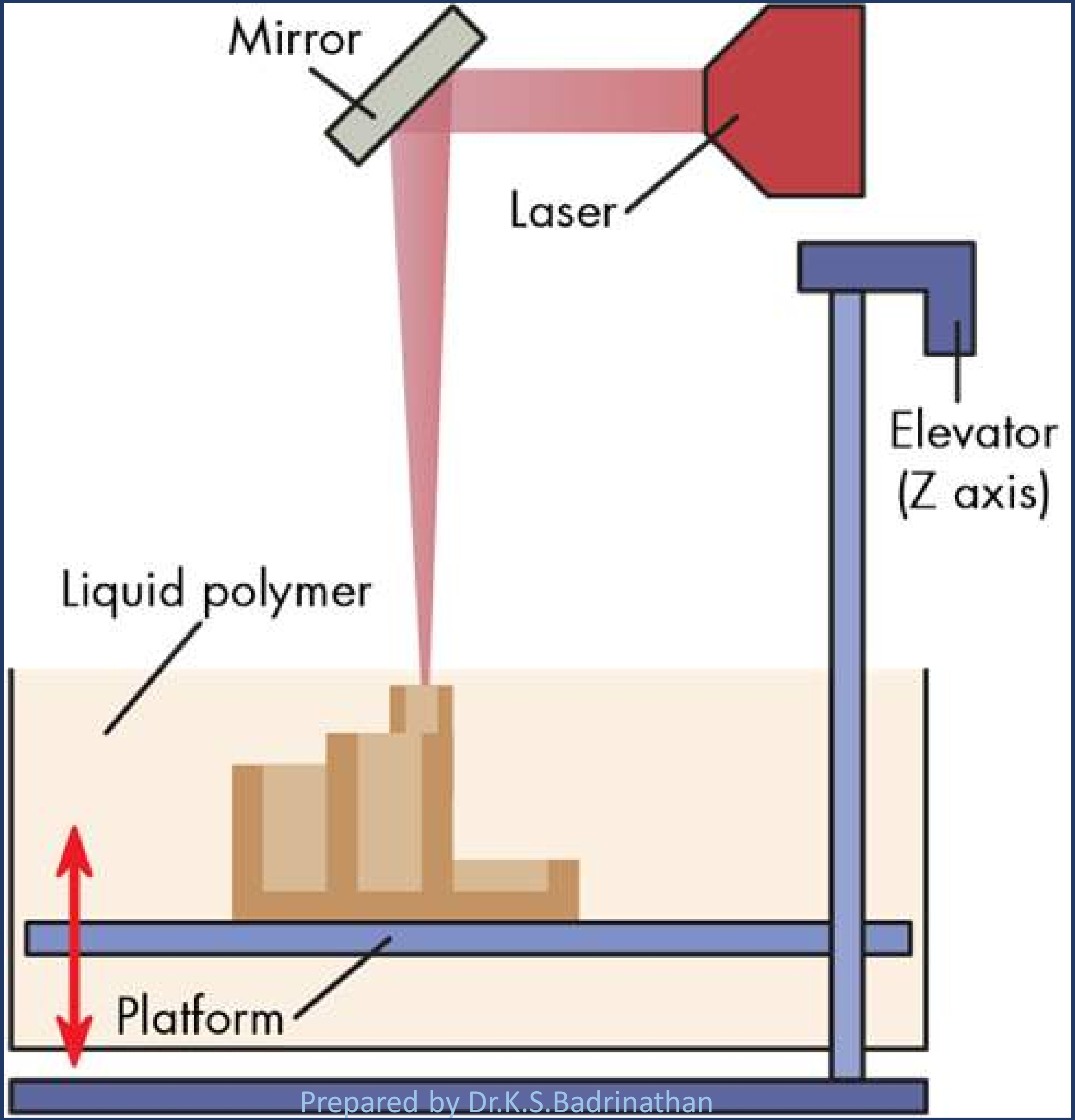
- Coherence - all the light waves move in phase together in both time and space



SLA Process



SLA Process



SLA Machine

3D Systems' SLA 7000

SLA Process Components

- Computer
- Control panel
- Laser
- Optical system
- Process chamber

SLA Process

- 3D CAD model file is loaded into the system
- Supports are designed to stabilize the part during building
- The translator converts the CAD data into a STL file
- control unit slices the model into a series of cross sections from 0.025 to 0.5 mm thick

SLA Process

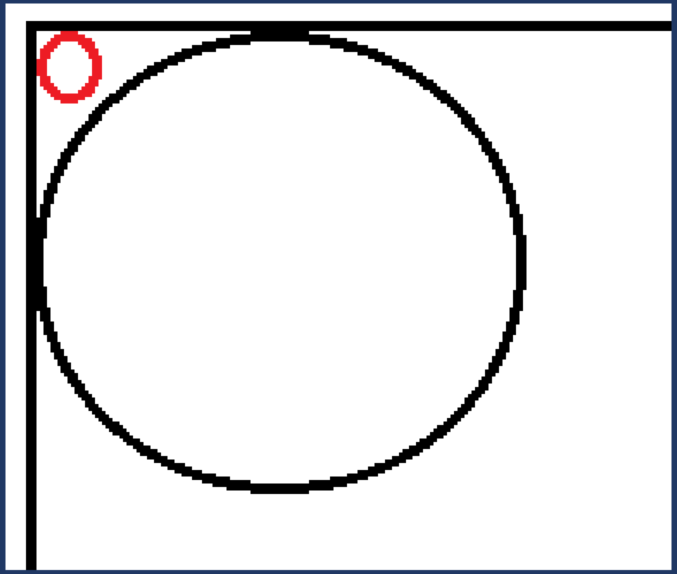
- vat is filled with the photo-curable liquid resin
- The computer-controlled optical scanning system directs and focuses the laser beam to solidify a 2D cross-section corresponding to the slice on the surface of the photo-curable liquid resin
- The elevator table then drops enough to cover the solid polymer with another layer of the liquid resin.

SLA Process

- A leveling wiper moves across the surfaces to recoat the next layer of resin on the surface.
- The laser then draws the next layer.
- This process continues building the part from bottom up, until the system completes the part.
- The part is then raised out of the vat and cleaned of excess polymer.

Process Parameters

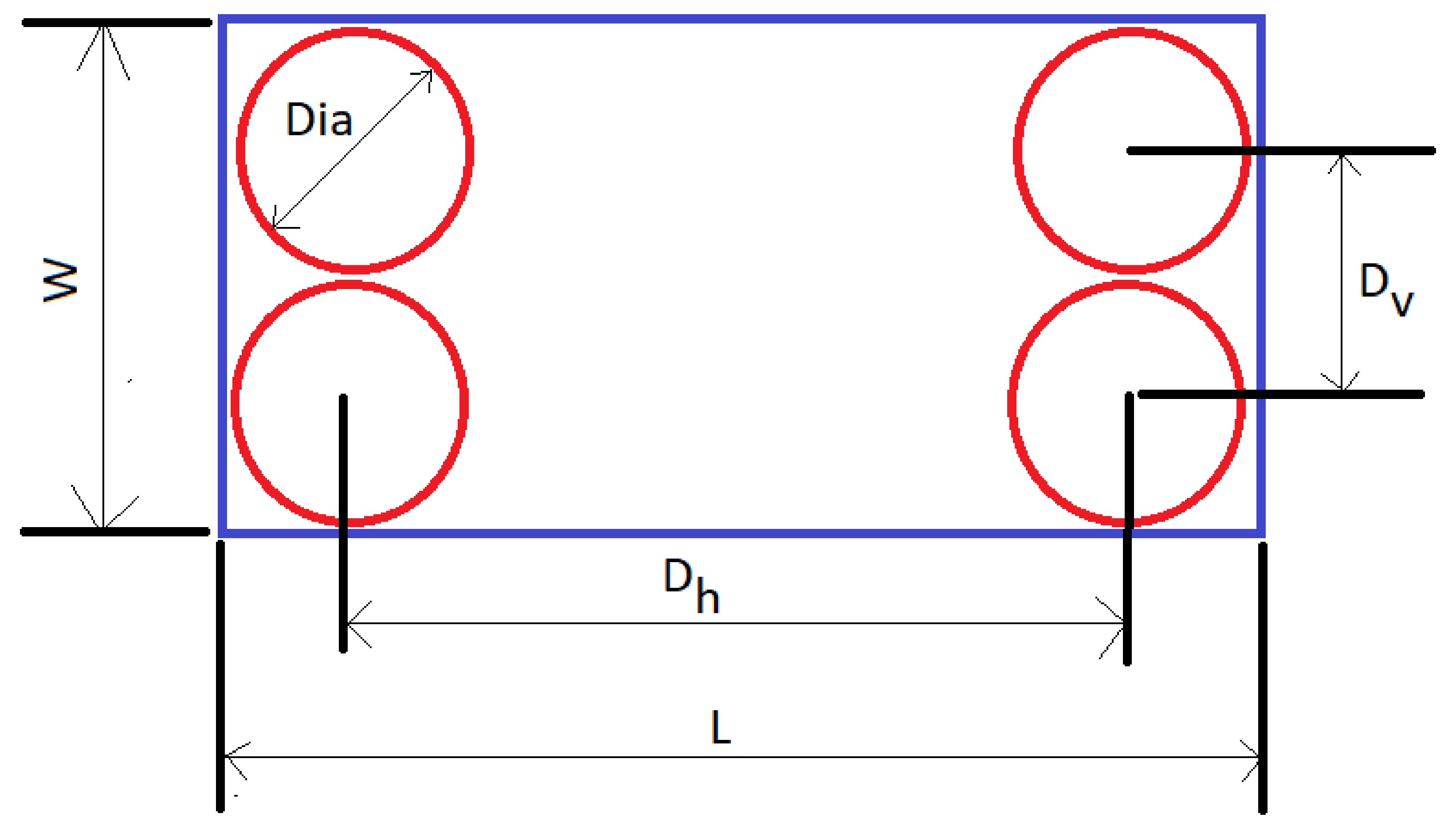
- Laser intensity
- Spot size of laser - dual spot laser
- Scanning speed
- Type of laser
    - He–Cd - Helium Cadmium
    - Nd:YVO_4 - Neodymium-doped yttrium orthovanadate



Process Parameters

- Laser intensity
    - For given scanning speed – high for thick layer; low for thin layer
- Spot size of laser
    - for broader sections – larger dia; for narrow sections – small dia.
- Scanning speed
    - for given laser intensity & spot size – slow for thick layer; fast for thin layer

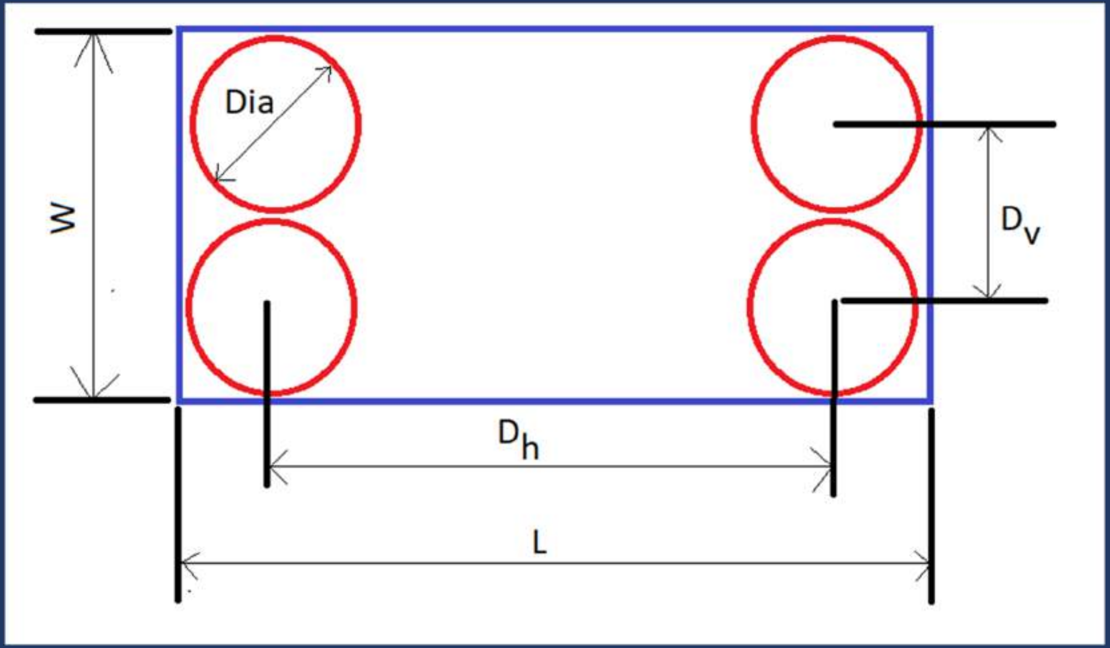
Scanning



Scan Time

Scan speed = 1 m/s

$D_h = 2$ m ; $D_v = 1$ m



Distance travelled, D = $(2xD_h) + D_v = 2x2 + 1 = 5$m

Time = 5/1 = 5 sec

Scan Time

Rectangular area of length 300 mm, width 200 mm; the spot size of laser is 50 mm; scanning speed 100 mm/s.

Calculate the scanning time.

Advantages of SLA

- Round the clock operation - continuously and unattended
- Good user support - The computerized process serves as a good user support.
- Build volumes - ranging from small to large
- Good accuracy
- Surface finish – best amongst RP technologies.
- Wide range of materials - general-purpose materials to specialty materials for specific applications.

Disadvantages of SLA

- Requires support structures - overhangs and undercuts must have supports

- Requires post-processing - removal of supports and other unwanted materials, which is tedious, time consuming and can damage the model.

- Requires post-curing - needed to cure the object completely and ensure the integrity of the structure.

Applications of SLA

- Models for conceptualization, packaging and presentation.
- Prototypes for design, analysis, verification and functional testing.
- Parts for prototype tooling and low volume production tooling.
- Patterns for investment casting, sand casting and molding.
- Tools for fixture and tooling design, and production tooling.

Solid Based Process

- The material is in the form of wire, roll, laminate & pellets
- Processes:
    - Laminated Object Manufacturing (LOM)
    - Fused Deposition Modeling (FDM)

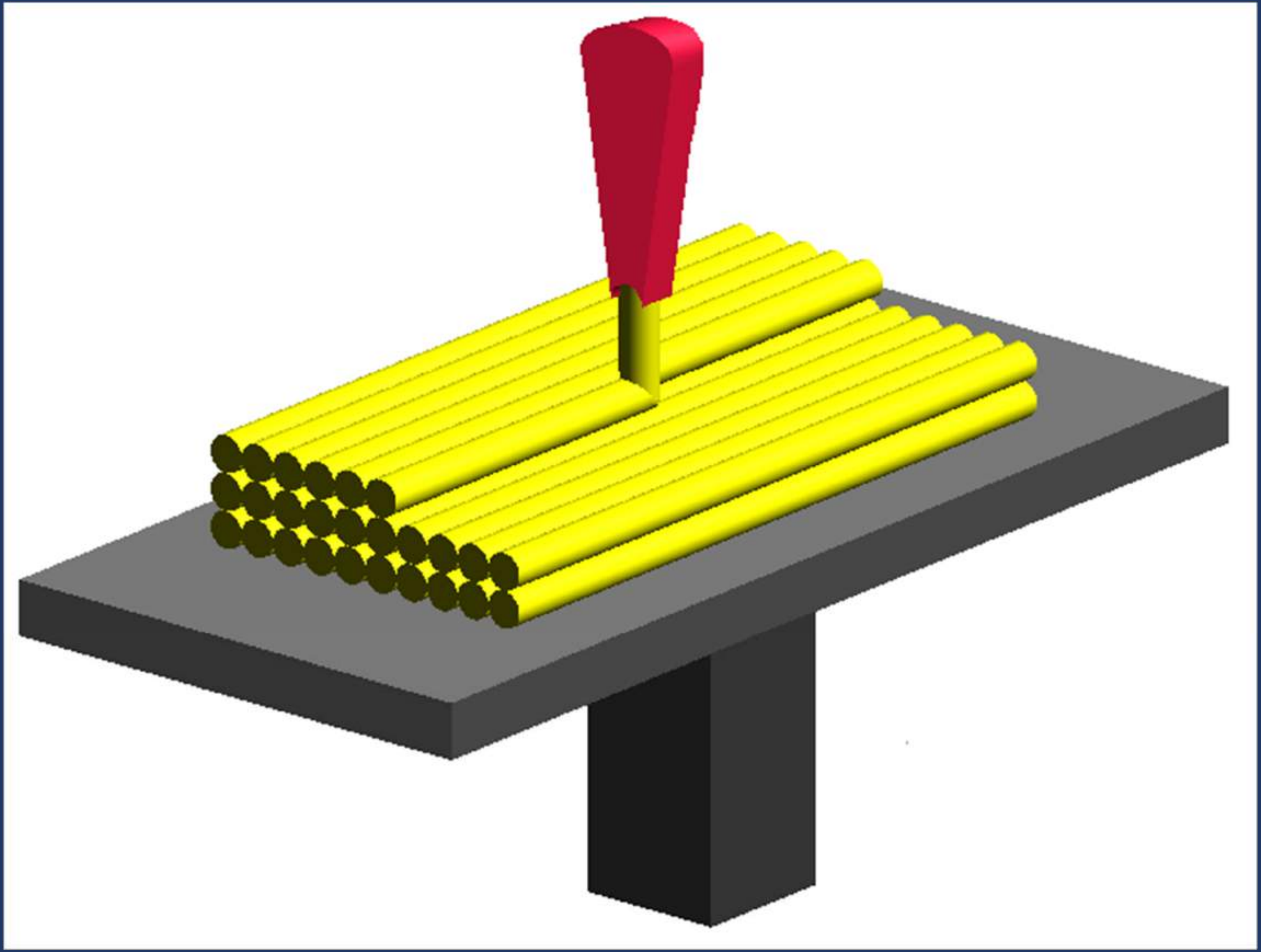
Solid based system

- Fused Deposition Modeling (FDM)
- First developed by Scott Cramp in 1988
- Stratasys Inc. - founded in 1989 developed most of the company’s products based on FDM technology.
- FDM uses the extrusion process to build 3D models

Principle - FDM

- Heating a filament of thermoplastic polymer and squeezing it out like toothpaste from a tube to form the RP layers.
- machines range from fast concept modelers to slower, high-precision machines.
- Materials include
  - Polyester
  - ABS
  - Elastomers
  - Investment casting wax.

Principle - FDM



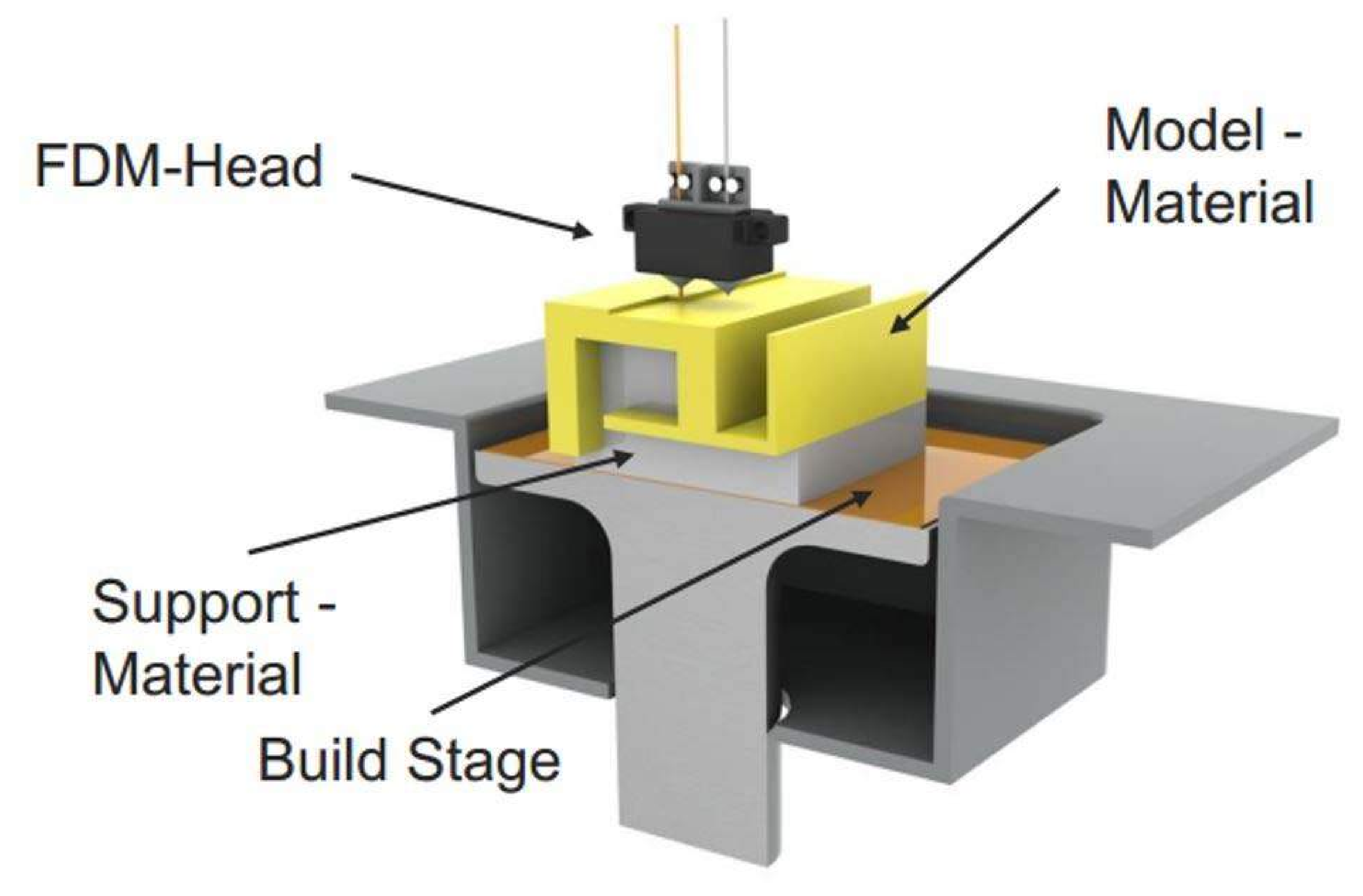
Principle - FDM

- Based on surface chemistry, thermal energy, and layer manufacturing technology
- The material in filament (spool) form is melted in a specially designed head, which extrudes on the model.
- As it is extruded, it is cooled and thus solidifies to form the model.
- Model is built layer by layer, like the other AM systems

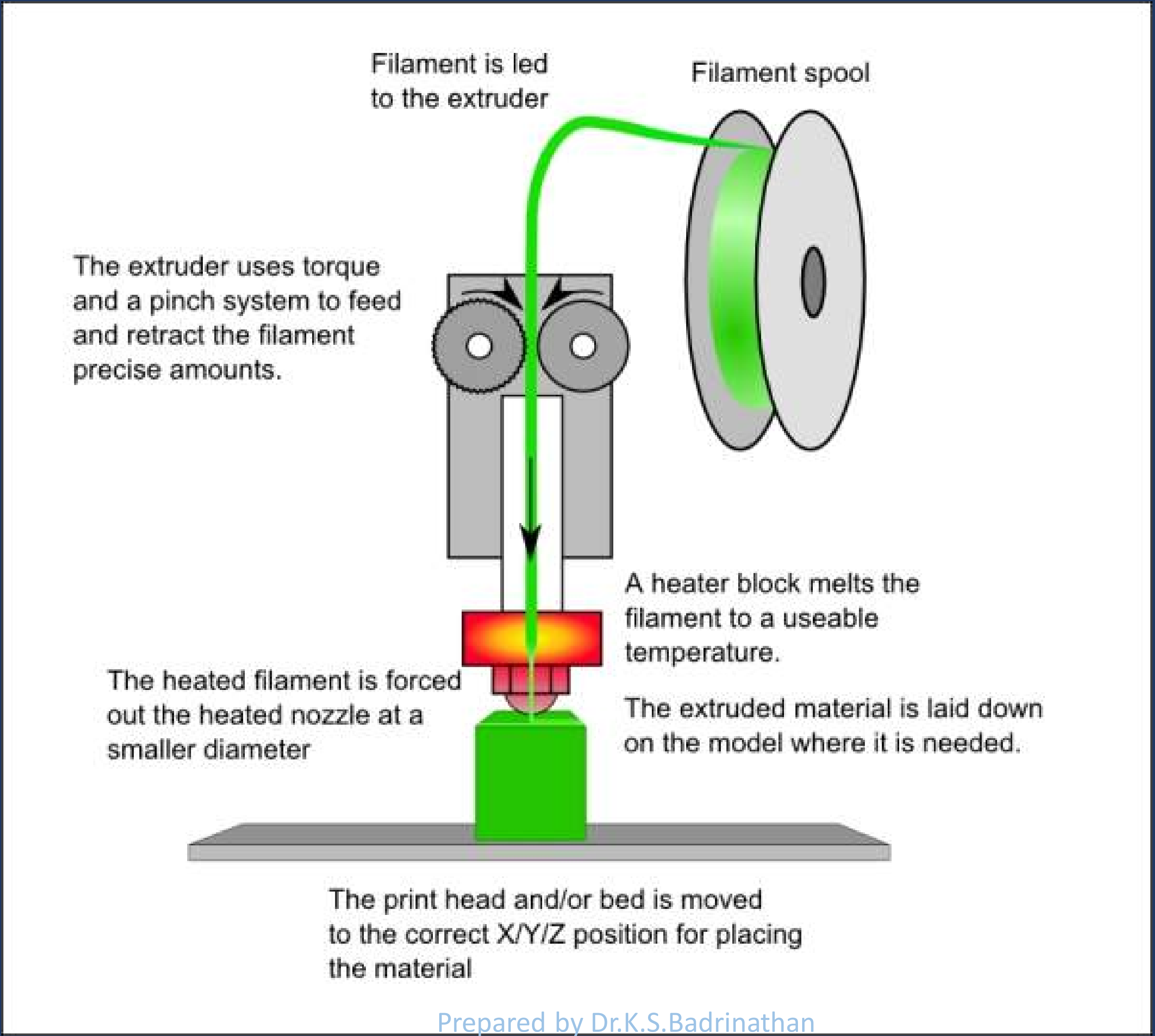
Specifications of FDM series

- **Build Size** : 600 × 500 × 600 mm
- **Accuracy** : ± 0.127 mm
- **Layer thickness** : 0.178 to 0.356 mm (SLA - 0.025)

FDM - Principle



FDM - Process



Filament is led to the extruder

Filament spool

The extruder uses torque and a pinch system to feed and retract the filament precise amounts.

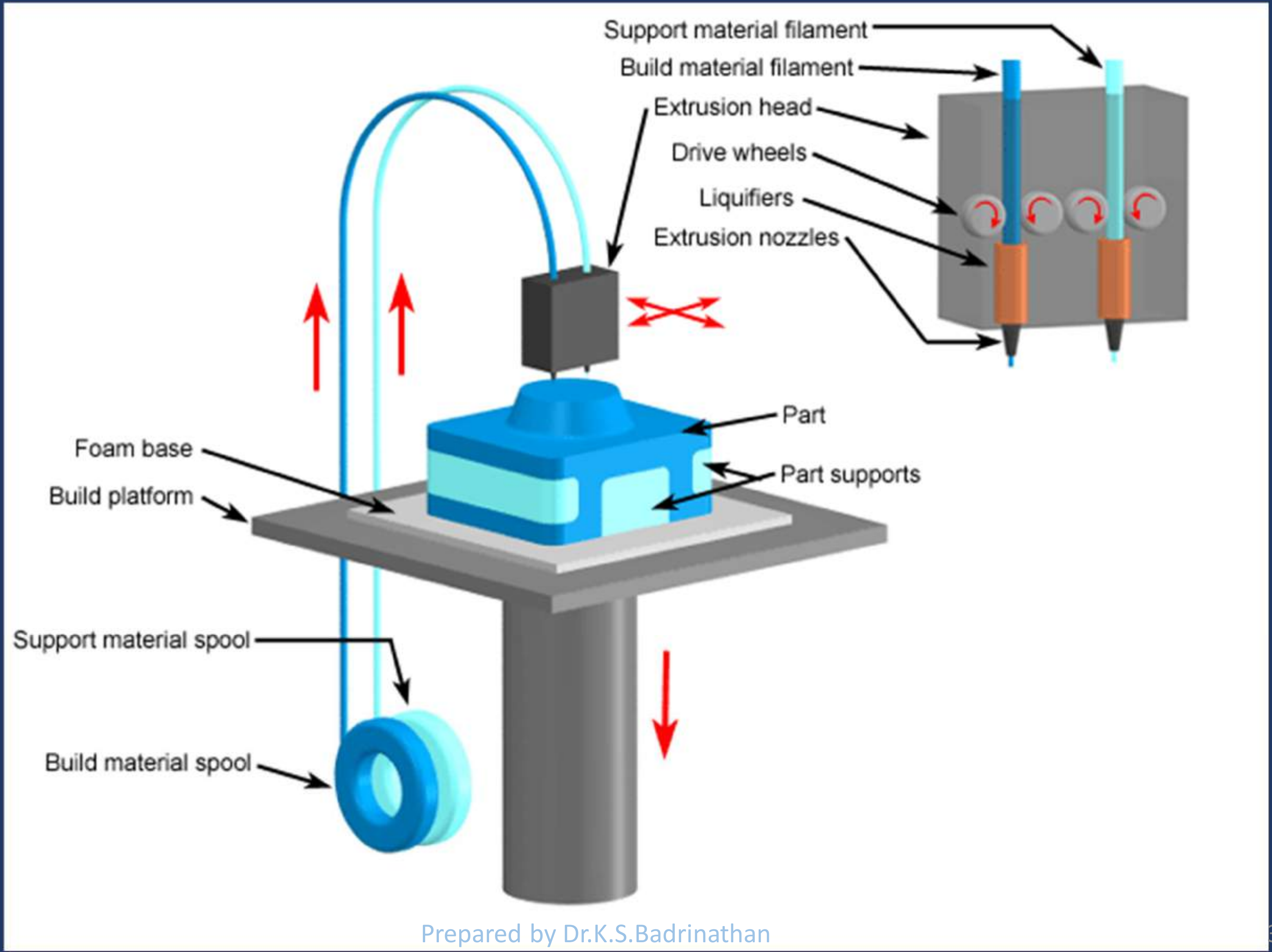
A heater block melts the filament to a useable temperature.

The heated filament is forced out the heated nozzle at a smaller diameter

The extruded material is laid down on the model where it is needed.

The print head and/or bed is moved to the correct X/Y/Z position for placing the material

FDM with Support Filament



FDM - Advantages

- **Fabrication of functional parts**. Fabricates prototypes with materials that are similar to that of the actual molded product.

- With ABS, it is able to fabricate fully functional parts that have 85% of the strength of the actual molded part.

- Useful in developing products that require quick prototypes for functional testing.

FDM - Advantages

- **Minimal wastage:** Parts are directly built by extruding semi-liquid melt onto the model. Thus only those material needed to build the part and its support are needed, and material wastages are kept to a minimum.

- Little need for cleaning up the model after it has been built.

FDM - Advantages

- **Ease of support removal.** With the use of Break Away Support System (BASS) and WaterWorks Soluble Support System, support structures generated during the FDM building process can be easily broken off or simply washed away.

- This makes it very convenient for users to get to their prototypes very quickly and there is very little or no post-processing necessary.

FDM - Advantages

- **Ease of material change.** Build materials, supplied in spool form (or cartridge form in the case of the Dimension or Prodigy Plus), are easy to handle and can be changed readily when the materials in the system are running low. This keeps the operation of the machine simple and the maintenance relatively easy.

FDM - Disadvantages

- **Restricted accuracy:** Parts built with the FDM process usually have restricted accuracy due to the shape of the material used, i.e., the filament form.
- Typically, the filament used has a diameter of 1.27 mm and this tends to set a limit on how accurately the part can be built.

FDM - Disadvantages

- **Slow process:** The building process is slow, as the whole cross-sectional area needs to be filled with building materials.

- Building speed is restricted by the extrusion rate or the flow rate of the build material from the extrusion head.

- As the build material used are plastics and their viscosities are relatively high, the build process cannot be easily speeded up.

FDM - Disadvantages

- **Unpredictable shrinkage:** As the FDM process extrudes the build material from its extrusion head and cools them rapidly on deposition, stresses induced by such rapid cooling invariably are introduced into the model.

- As such, shrinkages and distortions caused to the model built are a common occurrence and are usually difficult to predict, though with experience, users may be able to compensate for these by adjusting the process parameters of the machine.

Process Parameters

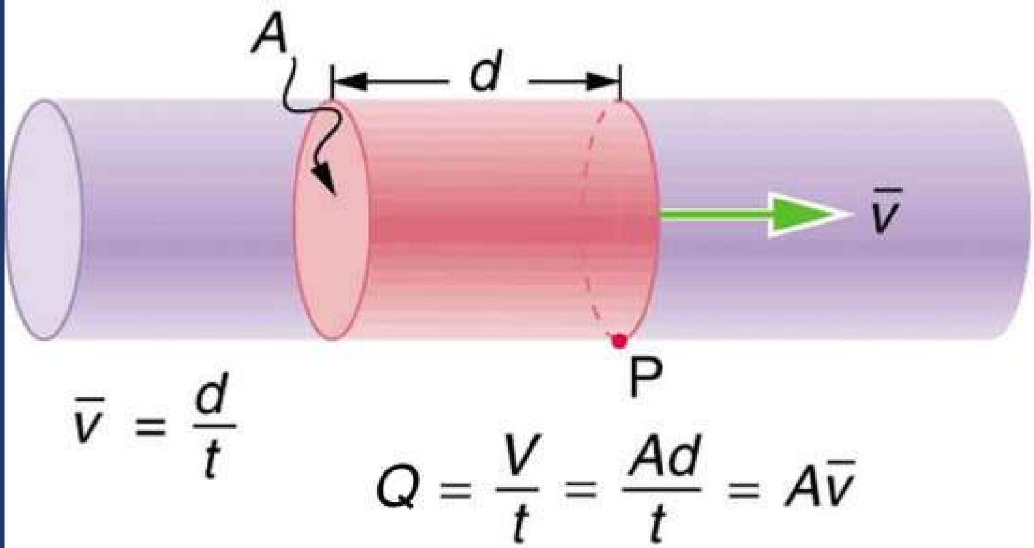
- material column strength
- material flexural modulus
- material viscosity
- positioning accuracy
- road widths
- deposition speed
- volumetric flow rate
- tip diameter
- envelope temperature
- part geometry.

FDM - Applications

- **Models for conceptualization and presentation**. Models can be marked, sanded, painted and drilled and thus can be finished to be almost like the actual product.
- **Prototypes for design, analysis and functional testing**. The system can produce a fully functional prototype in ABS. The resulting ABS parts have 85% of the strength of the actual molded part. Thus actual testing can be carried out, especially with consumer products.
- **Patterns and masters for tooling**. Models can be used as patterns for investment casting, sand casting and molding.

FDM – Build Time

- Process parameters:
  - Extrusion speed
  - tip diameter
- Tip diameter = 6 mm
- Extrusion Speed= 5 mm/s
- Build volume = 2000 mm^3



- Flow rate, mm^3/s = nozzle area x extrusion speed

  $= \pi r^2 \times 5 = 3.141 \times 9 \times 5 = 141.3$ mm^3/s

- Build time= Build volume/flow rate=

  2000 / 141.3 = 14.2 s

LAMINATED OBJECT MANUFACTURING (LOM)

- Cubic Technologies - December 2000 by Michael Feygin - inventor – LOM

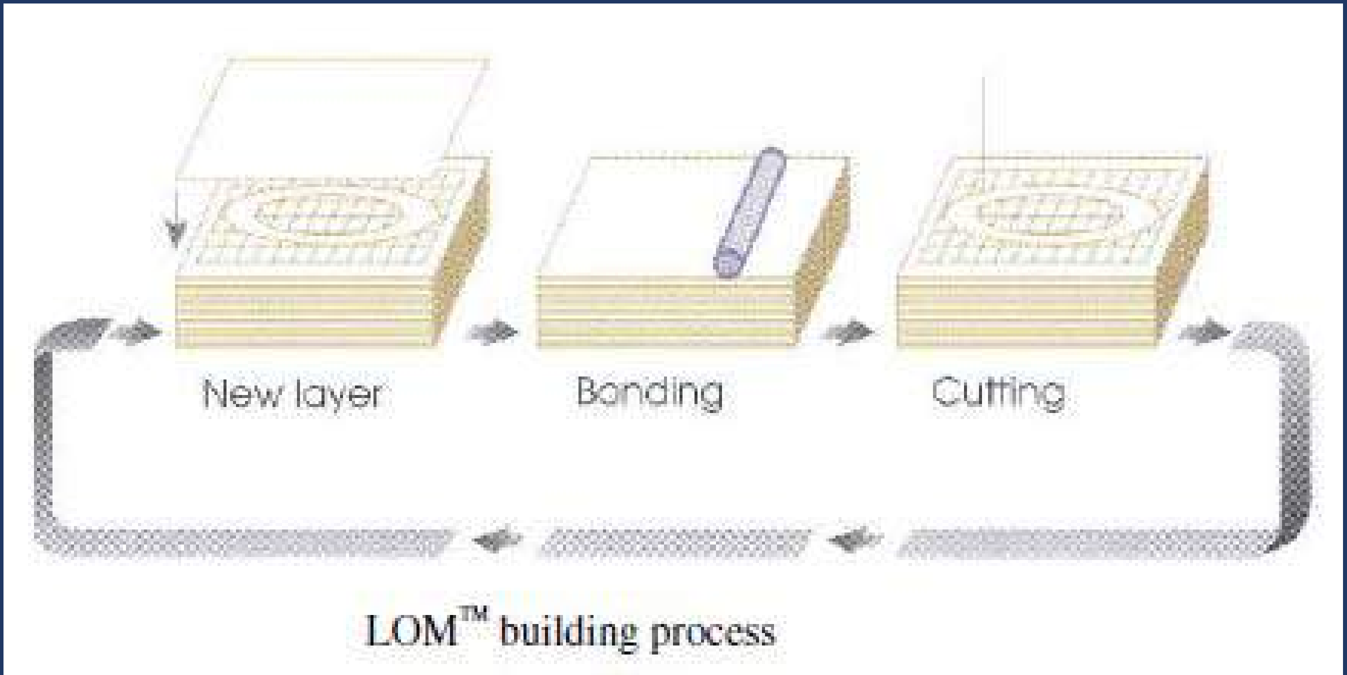
- 3D object is constructed from a solid CAD representation by sequentially laminating the part cross-sections.

- The process consists of three phases:
  - pre-processing
  - building
  - post-processing

LOM - Preprocessing

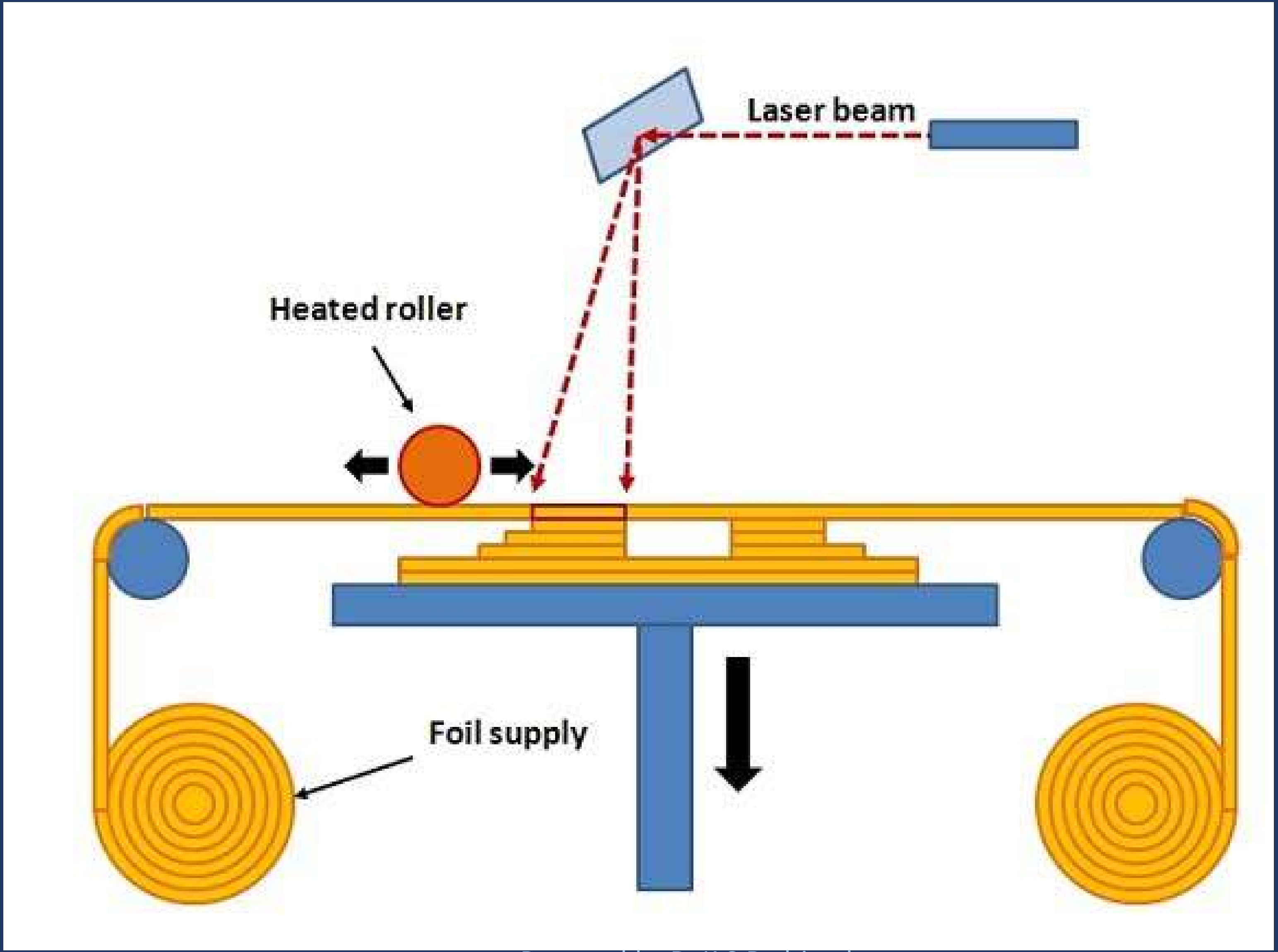
- Generate an image from a CAD-derived STL file of the part
- sort input data
- create secondary data structures.
- These are fully automated by LOMSlice^{TM}, the LOM^{TM} system software, which calculates and controls the slicing functions.
- Orienting and merging the part on the LOM^{TM} system are done manually.
- These tasks are aided by LOMSlice^{TM}, which provides a menu-driven interface to perform transformations (e.g., translation, scaling, and mirroring) as well as merges.

LOM -Building

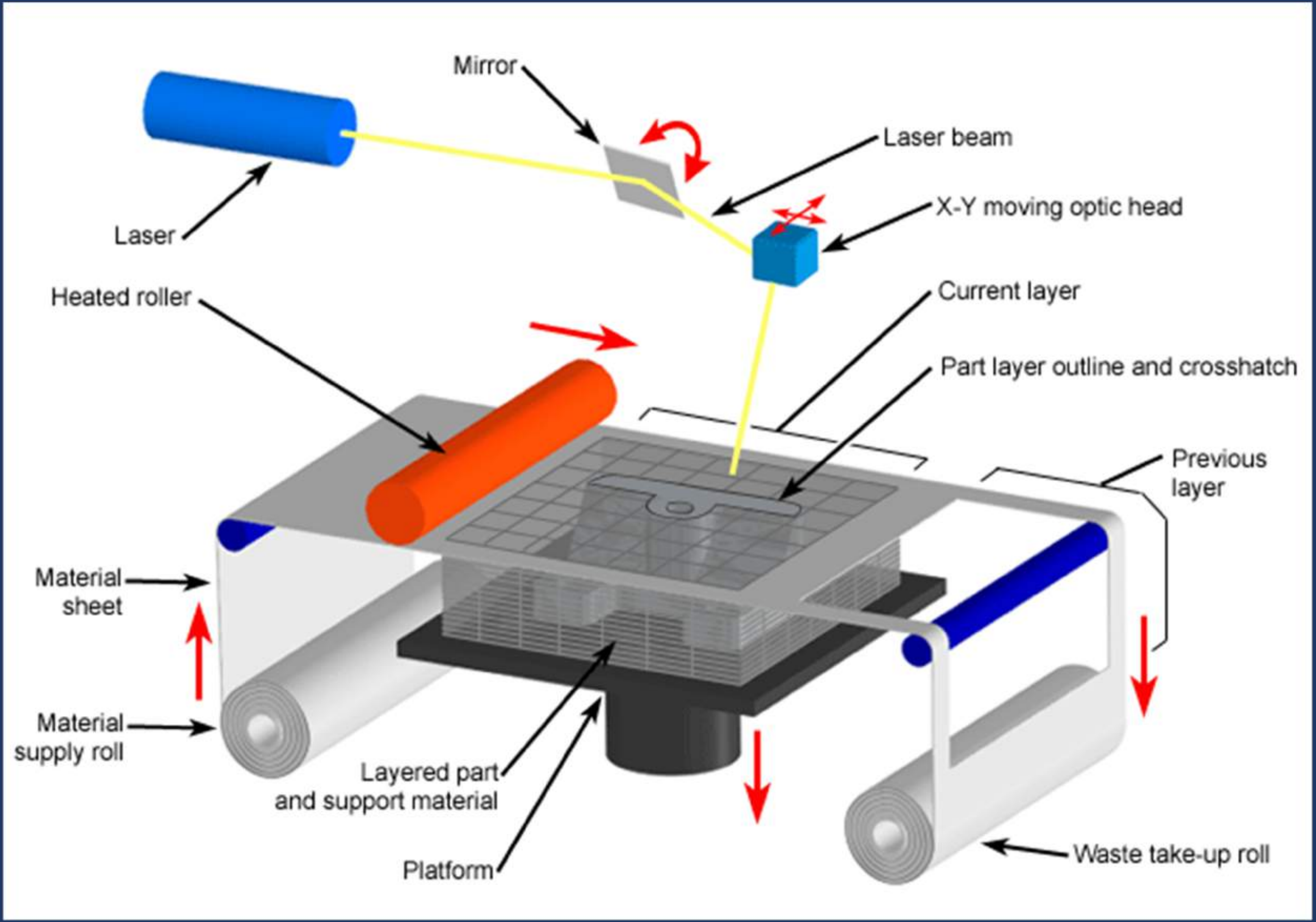


Thin layers of adhesive-coated (thermoplastic adhesive) material are sequentially bonded to each other and individually cut by a CO^2 laser beam

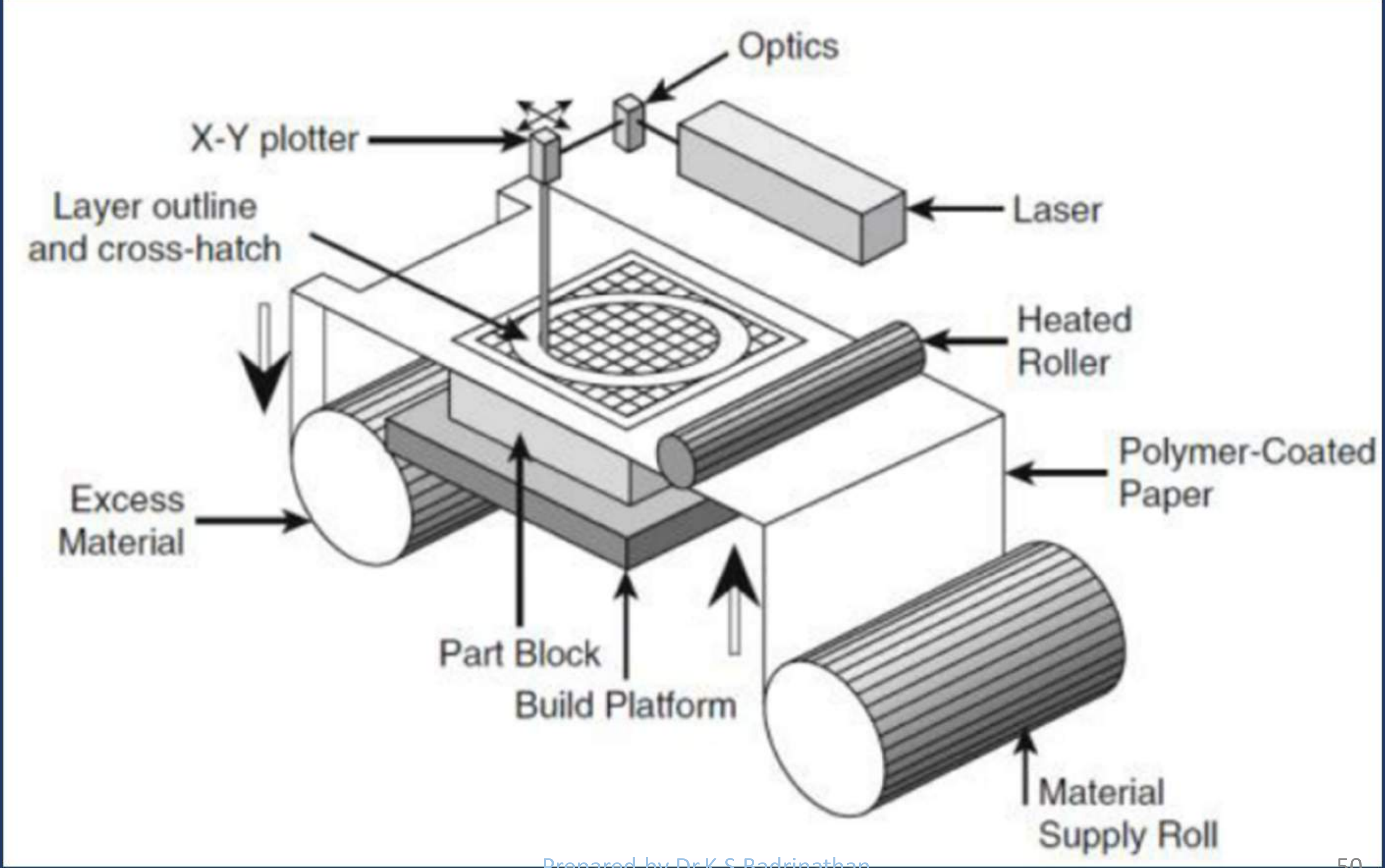
LOM -Building



LOM -Building



LOM -Building



LOM -Building

- LOMSlice^{TM} creates a cross-section of the 3D model equal to layer thickness (film thickness)
- The software then images crosshatches which define the outer perimeter and convert these excess materials into a support structure.
- Computer guides the focused laser beam to cut the cross-sectional outline, the crosshatches, and the model’s perimeter.

LOM -Building

- The laser beam power is designed to cut exactly the thickness of one layer of material at a time.

- 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.

Post-processing

- Post-processing, includes separating the part from its support material and finishing it.
- The metal platform, home to the newly created part, is removed from the LOM machine
- A hammer and a putty knife is required to separate the block from the platform.
- Crosshatched pieces may then be separated from the part using wood carving tools

Post-processing

- Finishing techniques, such as sanding, polishing, painting, etc. can be applied.

- After the part has been separated it is recommended that it be sealed immediately with urethane, epoxy, or silicon spray to prevent moisture absorption and expansion of the part.

- If necessary, LOM parts can be machined — by drilling, milling and turning

LOM - Materials

- Any sheet material with adhesive backing
- plastics
- metals
- ceramic tapes
- Most popular material is Kraft paper with a polyethylene-based heat seal adhesive system because it is widely available, cost-effective, and environmentally benign

LOM - Advantages

- **Wide variety of materials : A**ny material in sheet form can be used
- **Fast build time:** The laser does not scan the entire surface area of each cross-section, rather it only outlines its periphery. Suitable to produce large and bulky parts
- **High precision:** The feature-to-feature accuracy that can be achieved is usually better than 0.127 mm

LOM - Advantages

- **Support structure:** no need for additional support structure as the part is supported by its own material that is outside the periphery of the part built

- **Minimal post curing :** sheet materials are not subjected to either physical or chemical phase changes.

- The finished LOM parts do not experience warpage, internal residual stress, or other deformations.

LOM - Disadvantages

- **Precise power adjustment**. The power of the laser needs to be precisely controlled so that the laser cuts only the current layer of lamination and not penetrate the previously cut layers.

- Poor control of the cutting laser beam may cause distortion to the entire prototype

- **Fabrication of thin walls**: not well suited for building parts with delicate thin walls, especially in the Z-direction.

LOM-Applications

- Wide spectrum of industries:
    - industrial equipment for aerospace or
    - automotive industries,
    - Consumer products, and
    - medical devices ranging from instruments to prostheses

LOM-Applications

- **Visualization:** As the LOM 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.

- **Form, fit and function:** LOM parts lend themselves well for design verification and performance evaluation

LOM-Applications

- **Manufacturing:** The LOM 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, sand casting, injection molding, silicon rubber mold, vacuum forming and spray metal molding.

LOM-Applications

- **Rapid tooling**. Two-part negative tooling is easily created. Since the material is solid and inexpensive, bulk complicated tools are cost effective to produce.

- These wood-like molds can be used for injection of wax, polyurethane, epoxy or other low pressure and low temperature materials.

- Also, the tooling can be converted to aluminum or steel via the investment casting process for use in high temperature molding processes.

Build Time

- Process parameters
  - Laser travel speed, mm/s
  - Time taken by the roller, s
- A part has uniform cross-section. The perimeter of the cross-section is 150 mm. Time taken by the roller to stick one layer 5 seconds. Thickness of the sheet is 0.5mm. Laser speed is 10mm/s. The height of the part is 145mm. Calculate the build time.

Powder Based Process

- Powder in grain-like form is used
- Processes:
  - Selective Laser Sintering (SLS)
  - 3D Printing (3DP)
  - Direct Metal Laser Sintering (DMLS)
  - Laser Engineered Net Shaping (LENS)
  - Selective Laser Melting (SLM)
  - Electron Beam Melting (EBM)

Discrete Particle (Powder) AM Systems

- Selective Laser Sintering (SLS)
- Three-Dimensional Printing (3DP)
- Laser Engineered Net Shaping (LENS)

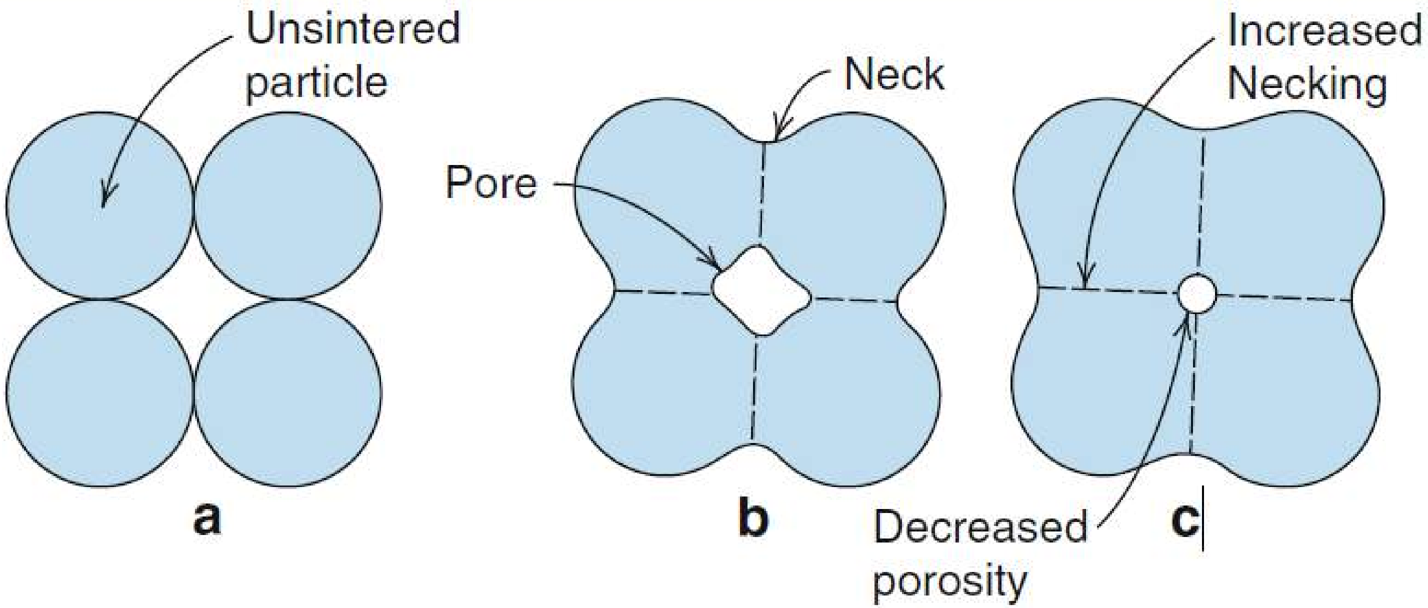
Selective Laser Sintering (SLS)

- DTM Corporation was established in 1987 to commercialize the SLS® technology
- First commercial machine in 1992
- DTM was bought over by 3D Systems in August 2001

SLS - Principle

- Parts are built by sintering when a CO_2 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 themselves and the previous layer to form a solid.
- The building of the part is done layer by layer
- 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.

SLS - Principle



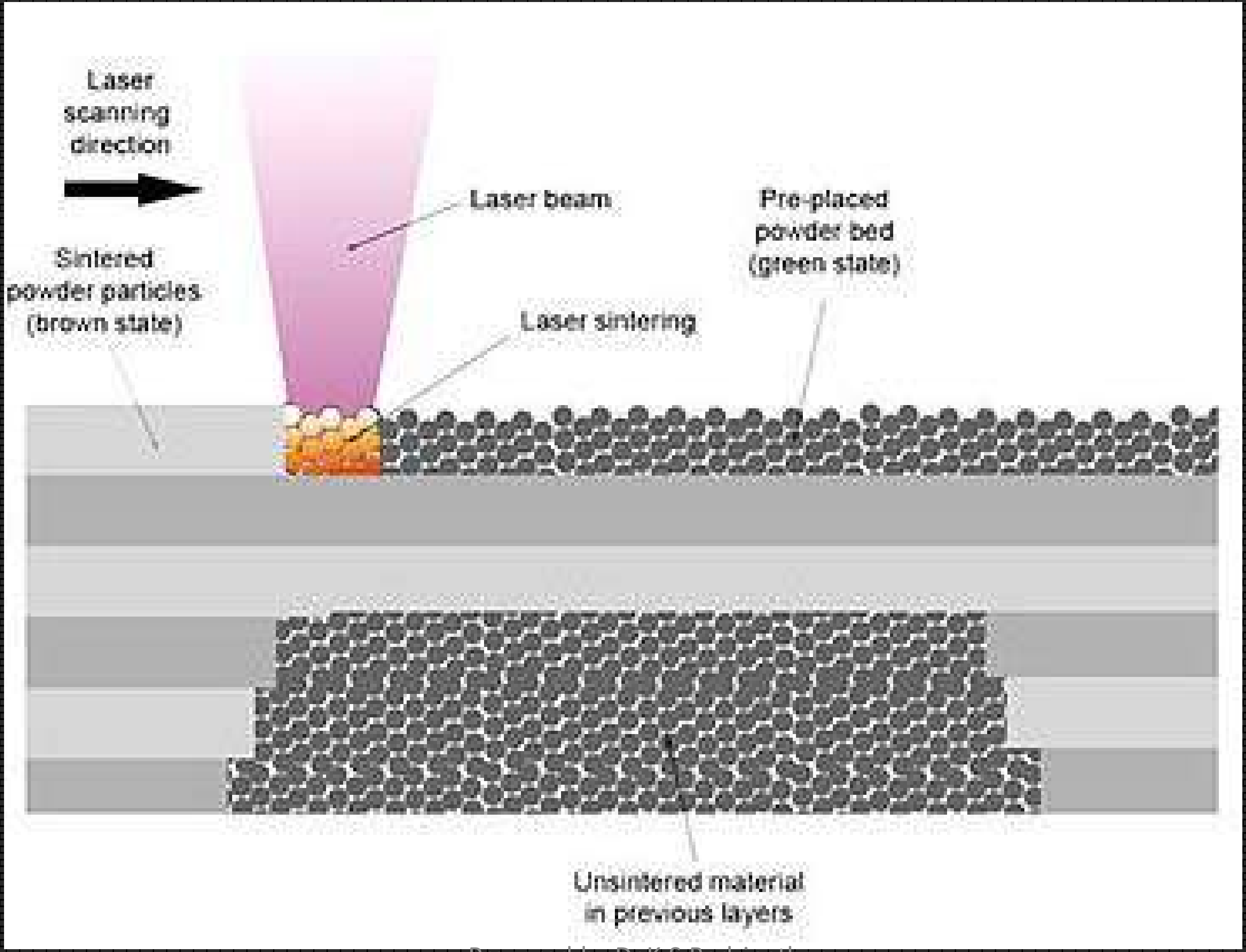
Solid-State Sintering.

(a) Closely packed particles prior to sintering

(b) Particles agglomerate at temperatures above one half of the absolute melting temperature

(c) As sintering progresses, neck size increases and pore size decreases

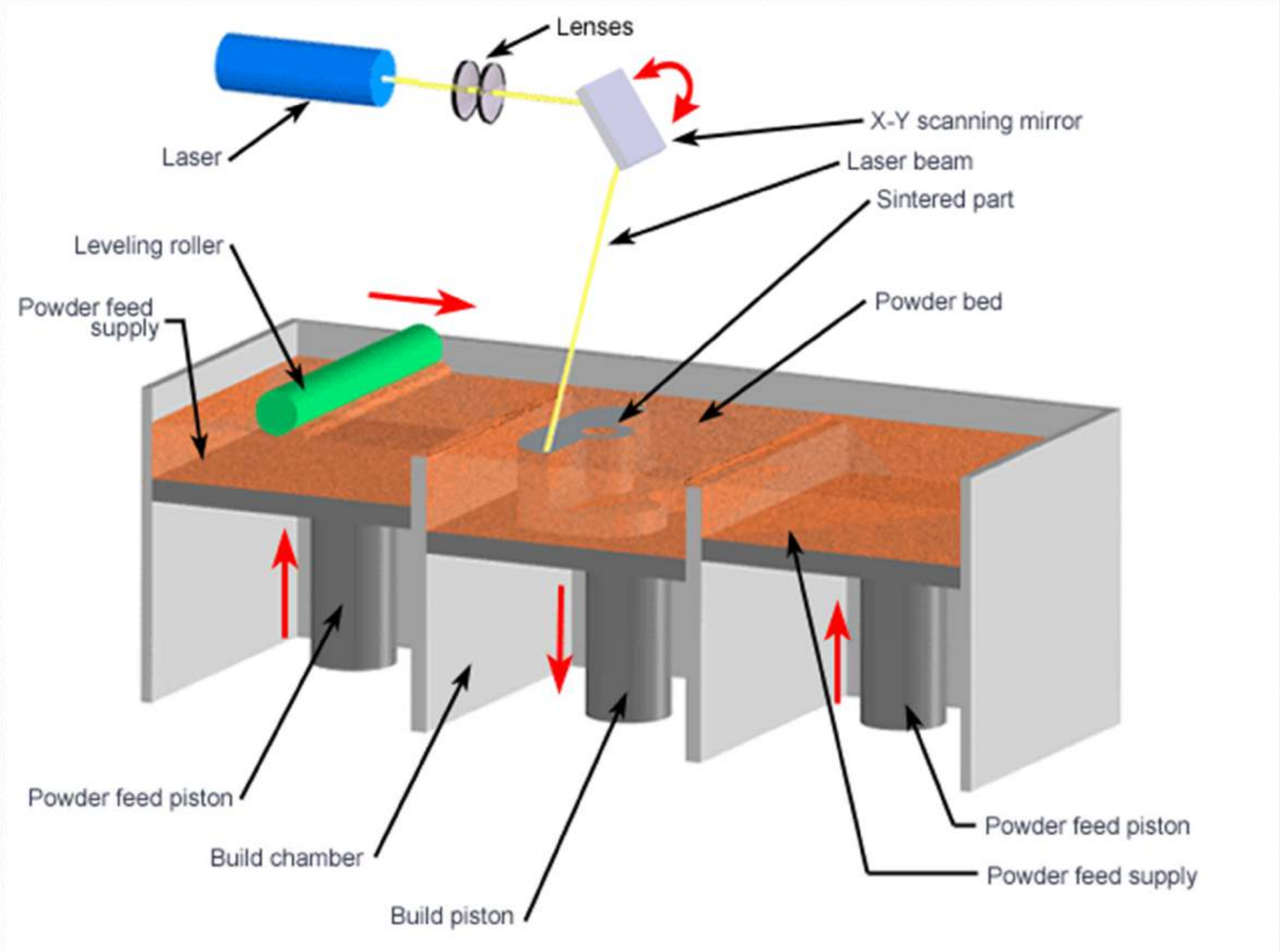
SLS - Process


Laser scanning direction
Laser beam
Pre-placed powder bed (green state)
Sintered powder particles (brown state)
Laser sintering
Unsintered material in previous layers

SLS - Process

- A thin layer of heat-fusible powder is deposited onto the part building chamber
- The bottom-most cross-sectional slice of the CAD part under fabrication is selectively “drawn” (or scanned) on the layer of powder by a heat-generating CO_2 laser
- The intensity of the laser beam is modulated to melt the powder only in areas defined by the part’s geometry.
- Surrounding powder remain a loose compact and serve as supports.
- An additional layer of powder is deposited via a roller mechanism on top of the previously scanned layer.

SLS - Process


Lenses
Laser
X-Y scanning mirror
Laser beam
Sintered part
Leveling roller
Powder feed supply
Powder bed
Powder feed piston
Build chamber
Build piston
Powder feed piston
Powder feed supply

SLS - Materials

- Polyamide. Trade named “DuraForm”, is used to create rigid and rugged plastic parts for functional engineering environments.
- Thermoplastic elastomer. Flexible, rubber-like parts can be prototyped. The material is impermeable to water and ideal for sports shoe applications and engineering seals.
- Polycarbonate. An industry-standard engineering thermoplastic. Suitable for concept and functional models and prototypes, investment casting patterns for metal prototypes and cast tooling

SLS - Materials

- Nylon. industry-standard engineering thermoplastic.
- It is one of the most durable rapid prototyping materials currently available in the industry, and it offers substantial heat and chemical resistance.
- Metal. polymer coated stainless steel powder is infiltrated with bronze.
- Trade named “LaserForm ST-100”, the material is excellent for producing core inserts and preproduction tools for injection molding prototype polymer parts.
- The material exhibits high durability and thermal conductivity and can be used for relatively large-scale production tools

SLS - Materials

- Ceramics. Trade named “SandFormTM Zr” and “SandformTM Si”, these use zircon and silica coated with phenolic binder to produce complex sand cores and molds for prototype sand castings of metal parts

SLS – Process Parameters

- Properties of powdered materials and its mechanical properties after sintering
- Accuracy of the laser beam
- Scanning pattern
- Exposure parameters
- Resolution of the machine.

SLS - Advantages

- Good part stability. The process and materials provide for directly produced functional parts to be built.
- Wide range of processing materials. nylon, polycarbonates, metals and ceramics are available, thus providing flexibility and a wide scope of functional applications.
- No part supports required. does not require CAD developed support structures. This saves the time required for support structure building and removal.
- Little post-processing required. requires only minimal post-processing such as particle blasting and sanding.

SLS - Advantages

- No post-curing required. laser sintered part is solid enough and does not require further curing.
- Advanced software support. Good Graphical User Interface (GUI).
- It allows for streamlined parts scaling, advanced nonlinear parts scaling, in-progress part changes, build report utilities and is available in foreign languages

SLS - Disadvantages

- Large physical size of the unit. requires a relatively large space to house it. Additional storage space is required to house the inert gas tanks used for each build.
- High power consumption. requires high power consumption due to the high wattage of the laser required to sinter the powder particles together.
- Poor surface finish. The as-produced parts tend to have poorer surface finish due to the relatively large particle sizes of the powders used.

SLS - Applications

- Concept models. Physical representations of designs used to review design ideas, form and style.
- Functional models and working prototypes. Parts that can withstand limited functional testing, or fit and operate within an assembly.

SLS - Applications

- Polycarbonate patterns (RapidCasting^{TM}). Patterns produced using polycarbonate, then cast in the metal of choice through the standard investment casting process. These build faster than wax patterns and are ideally suited for designs with thin walls and fine features. These patterns are also durable and heat resistant.
- Metal tools (RapidTool^{TM}). Direct rapid prototype of tools of molds for small or short production runs.

THREE-DIMENSIONAL PRINTING (3DP)

- Z Corporation - incorporated in 1994
- first 3D Printer, based on three-dimensional technology (3DP) in 1997
- Technology was invented and patented at the Massachusetts Institute of Technology
- Subsequently licensed and further developed by Z Corporation

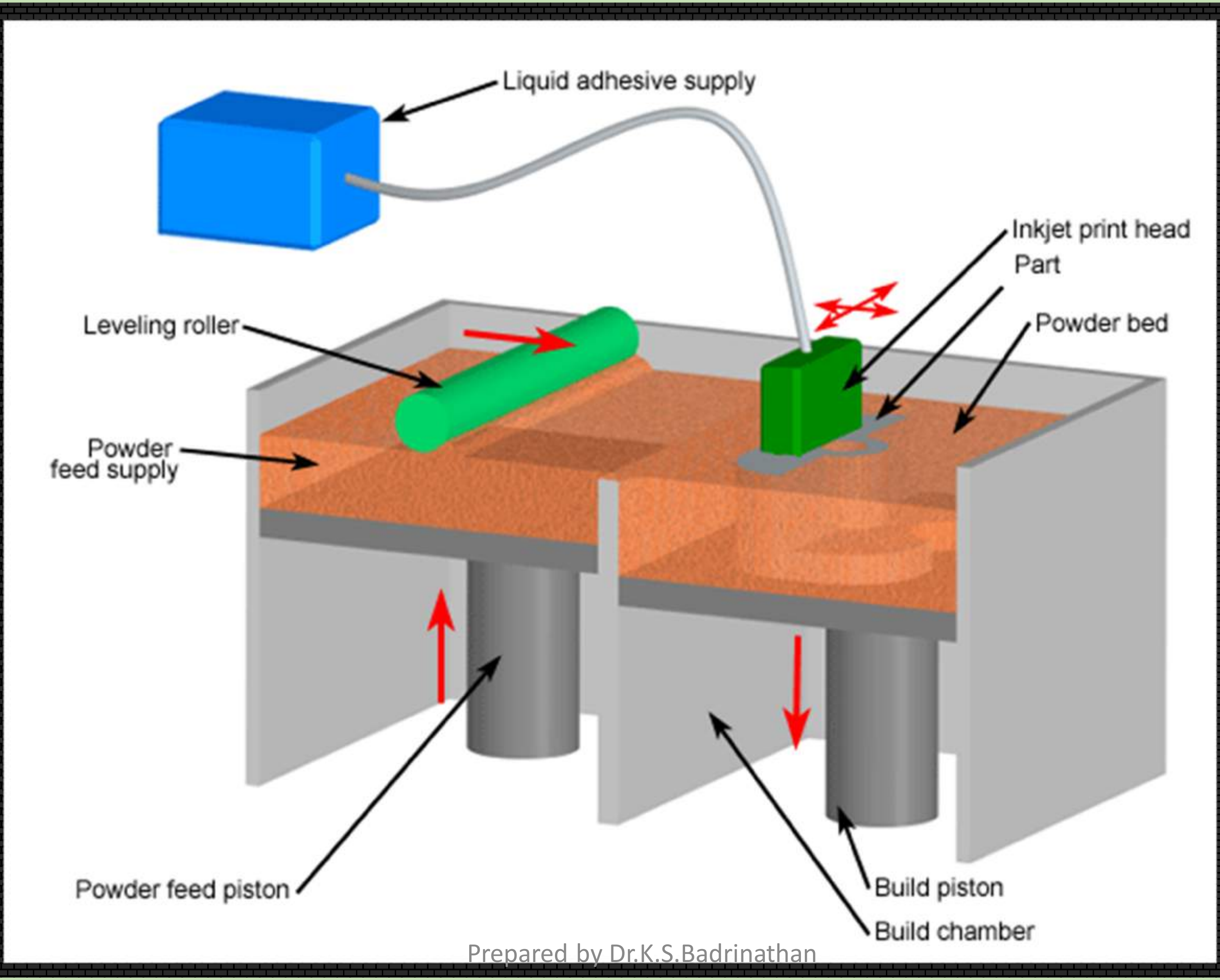
3DP - Process

- The machine spreads a layer of powder from the feed box to cover the surface of the build piston.
- The printer then prints binder solution onto the loose powder, forming the first cross-section.
- The powder is glued together at where the binder is printed.
- The remaining powder remains loose and supports the layers that will be printed above.
- When the cross-section is completed, the build piston is lowered, a new layer of powder is spread over its surface, and the process is repeated.

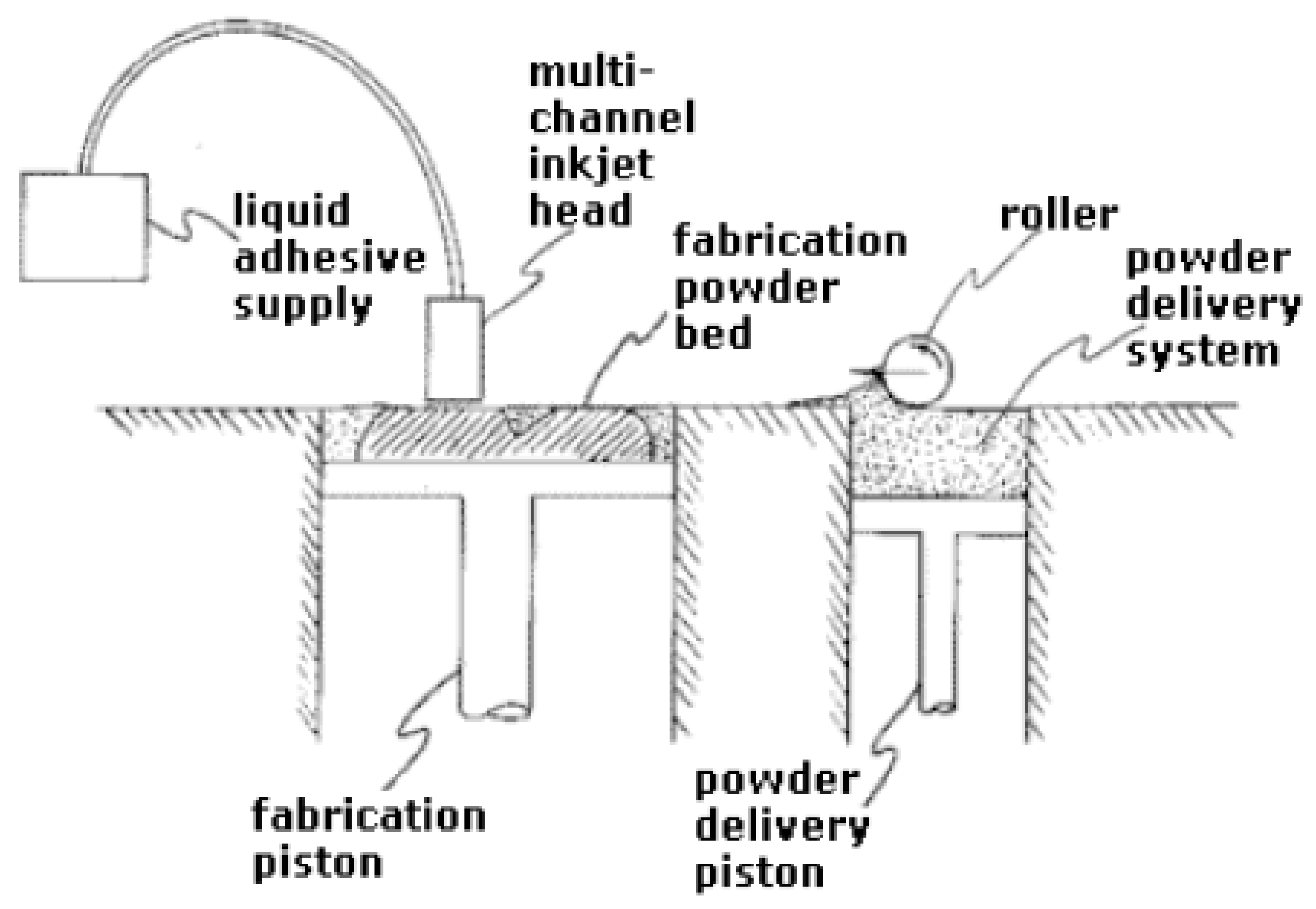
3DP - Process

- The excess powder is vacuumed, and the parts are lifted from the bed.
- For a quick design review, parts can be left raw or "green."
- To produce a more robust model, parts can be dipped in wax.
- For a robust model that can be sanded, finished and painted, the part can be infiltrated with a resin or urethane.

3DP - Process


Liquid adhesive supply
Inkjet print head
Part
Powder bed
Leveling roller
Powder
feed supply
Powder feed piston
Build piston
Build chamber

3DP - Process


liquid adhesive supply
multi-channel inkjet head
fabrication powder bed
roller
powder delivery system
fabrication piston
powder delivery piston

3DP - Advantages

- High speed. Fastest 3D printer to date. Each layer is printed in seconds, reducing the prototyping time of a hand-held part to 1 to 2 hours.

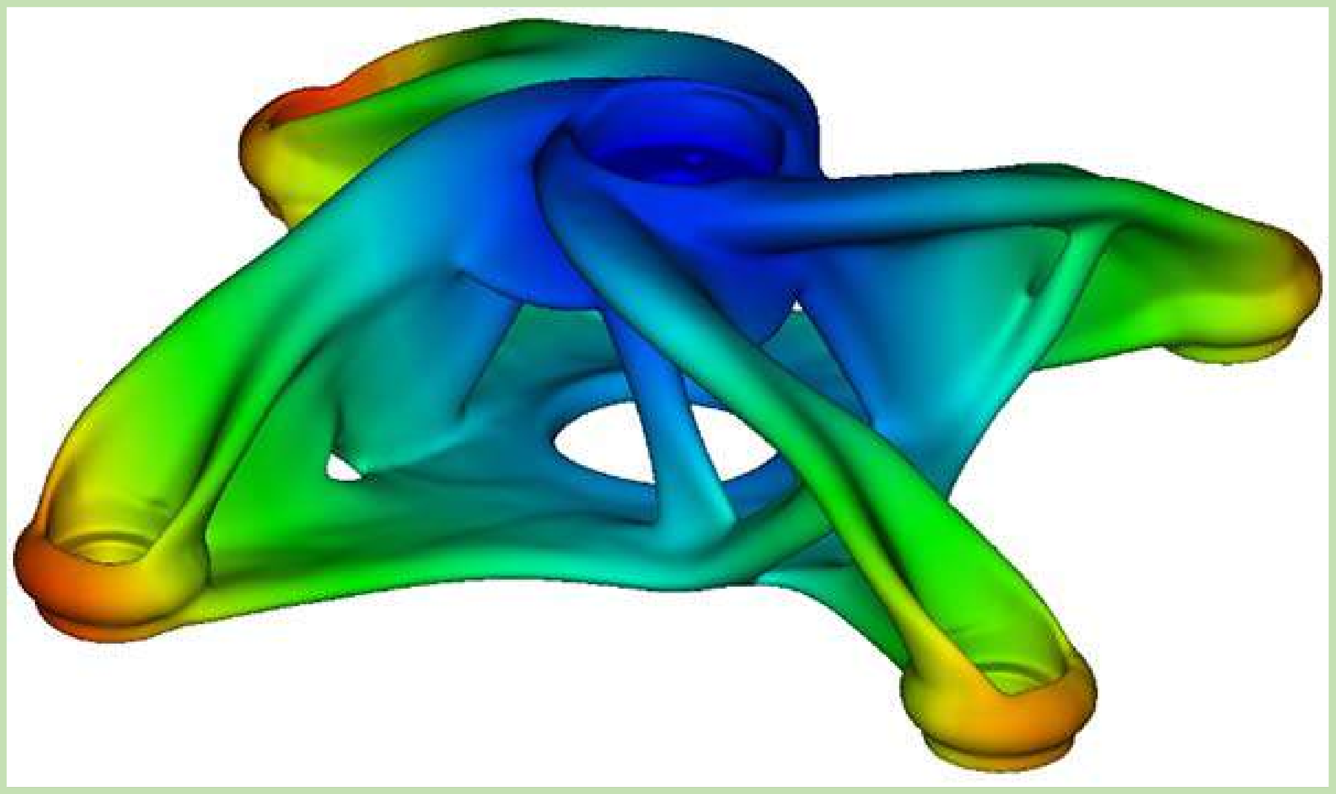
- Versatile. used for automotive, packaging, education, footwear, medical, aerospace and telecommunications industries.

- Simple to operate. does not require a designated technician to build a part.

3DP - Advantages

- No separate support structure is needed
- No wastage of materials. Unused powder can be reused.
- Color. Enables complex color schemes from a full 24-bit palette of colors.

3DP – Colour Part



3DP - Disadvantages

- Limited functional parts. Relative to the SLS, parts built are much weaker, thereby limiting the functional testing capabilities.
- Limited materials. only starch and plaster-based materials, with the added option to infiltrate wax
- Poor surface finish. Parts have a relatively poorer surface finish and post-processing is frequently required.

3DP - Applications

- Manufacturing
- Medicine
- Architecture
- Custom art and design

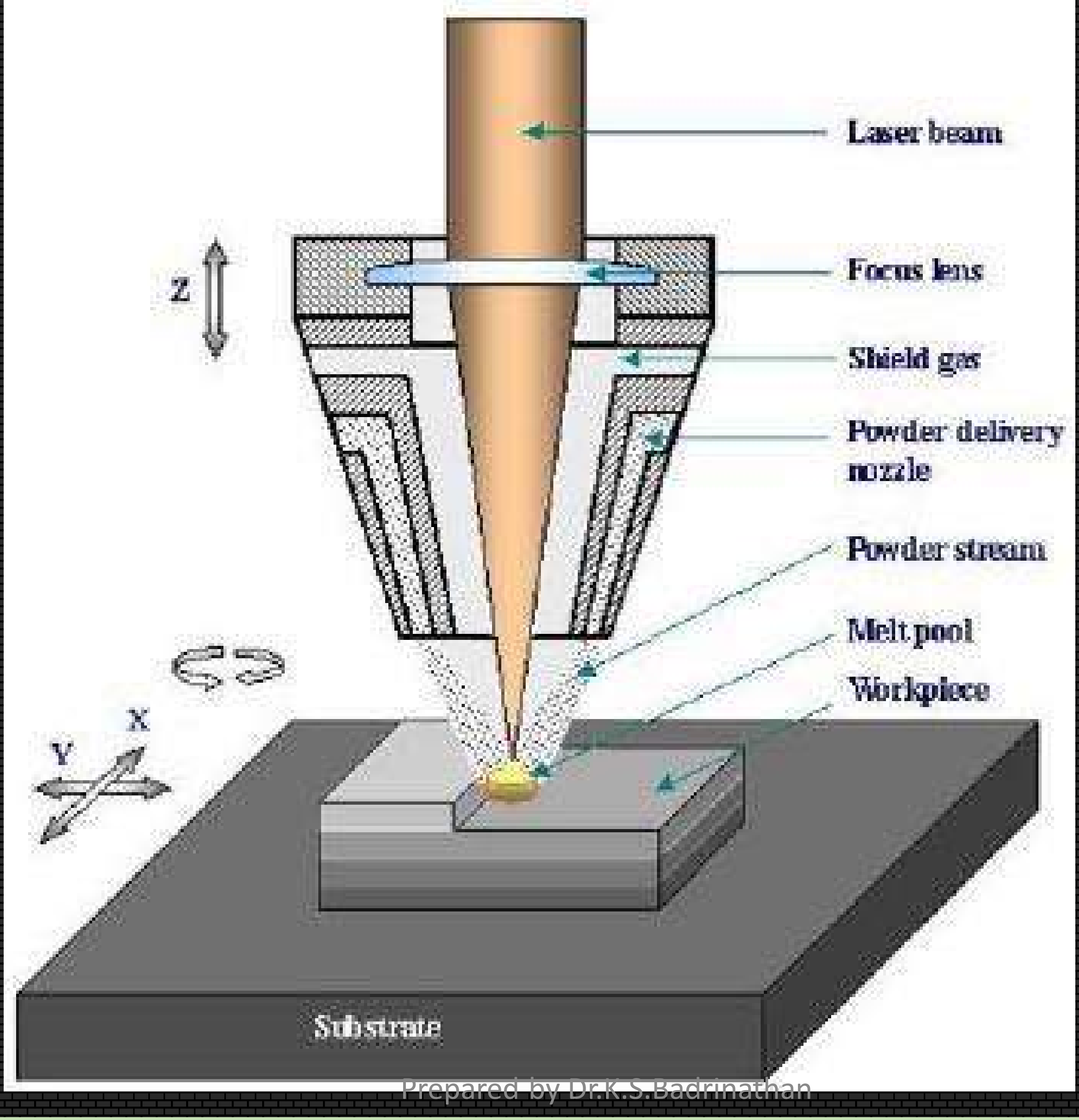
Laser Engineered Net Shaping (LENS)

- Optomec Inc. - incorporated in 1992
- Originally developed by Sandia National Laboratories, California.
- Since 1997, Optomec has focused on commercializing

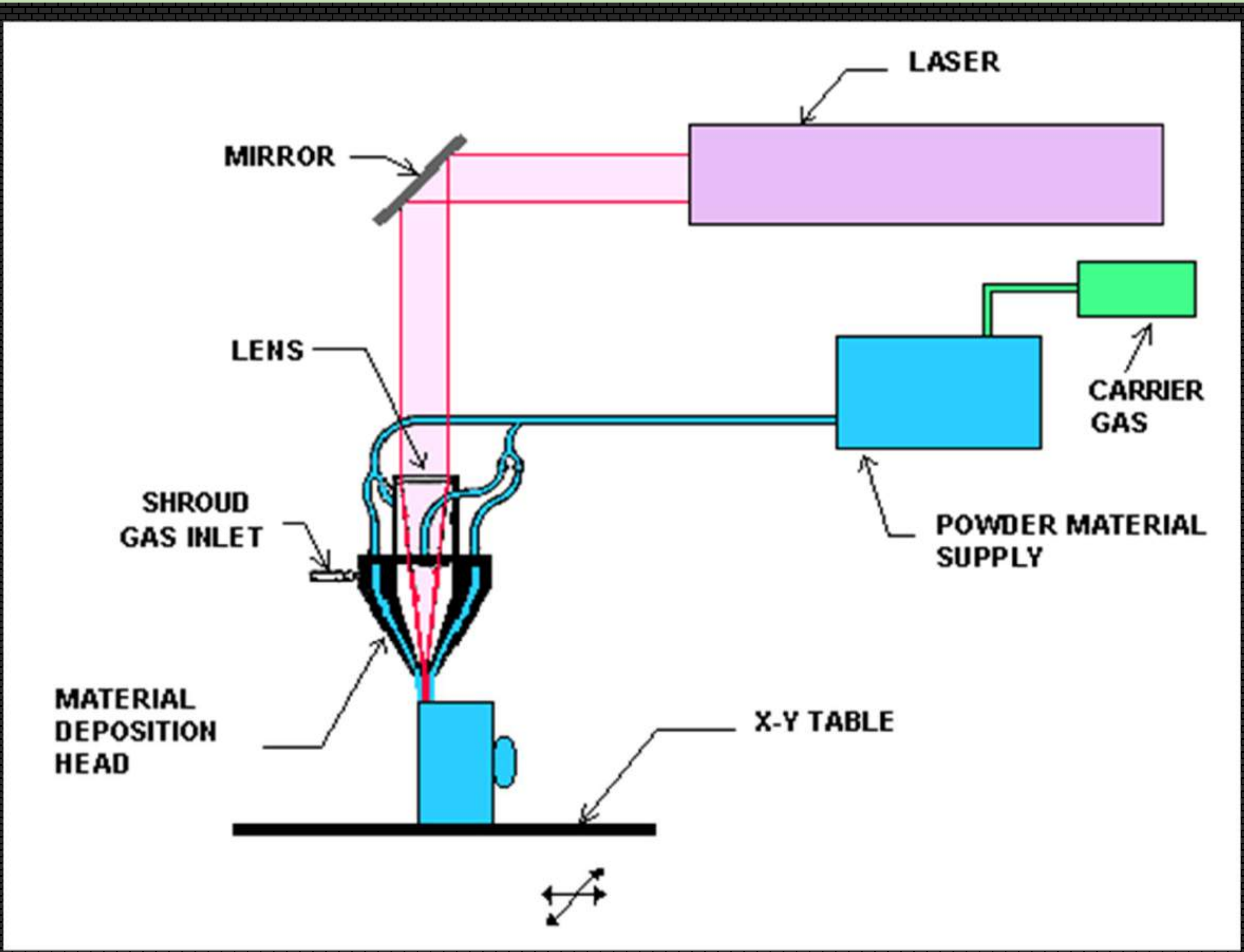
LENS - Principle

- High powered Nd:YAG (Neodymium-doped Yttrium Aluminium Garnet) laser focused onto a metal substrate creates a molten puddle on the substrate surface.
- Powder is then injected into the molten puddle to increase material volume.
- A “printing” motion system moves a platform horizontally and laterally as the laser beam traces the cross-section of the part being produced.
- After formation of a layer of the part, the machine’s powder delivery nozzle moves upwards prior to building next layer.

LENS - Process



LENS - Process



LENS - Process

- A deposition head supplies metal powder to the focus of a high-powered Nd:YAG laser beam to be melted.
- The laser is focused on a particular spot by a series of lenses, and a motion system underneath the platform moves horizontally and laterally as the laser beam traces the cross-section of the part being produced.
- The fabrication process takes place in a low-pressure argon chamber for oxygen-free operation in the melting zone, ensuring that good adhesion is accomplished.
- When a layer is completed, the deposition head moves up and continues with the next layer.

LENS - Advantages

- Superior material properties. produces fully dense metal parts .
- The microstructure produced is also relatively good.
- Complex parts. Functional metal parts with complex features are the forte of the LENS system.
- Reduced post-processing requirements. Post-processing is minimized, thus reducing cycle time.

LENS - Disadvantages

- Limited materials. The process is currently narrowly focused to produce only metal parts.
- Large physical unit size. The unit requires a relatively large area to house.
- High power consumption. The laser system requires very high wattage.

LENS - Applications

- Build mold and die inserts
- Producing titanium parts in racing industry
- Fabricate titanium components for biological implants
- Produce functionally gradient structures

END OF UNIT - II

ME18002 – 3DP & D

Unit – 3

DESIGN FOR AM

Unit – 3 : Contents

- DFAM concepts and objectives
- AM unique capabilities
- Exploring design freedoms
- Design for AM
- Guidelines for process selection

DFMA

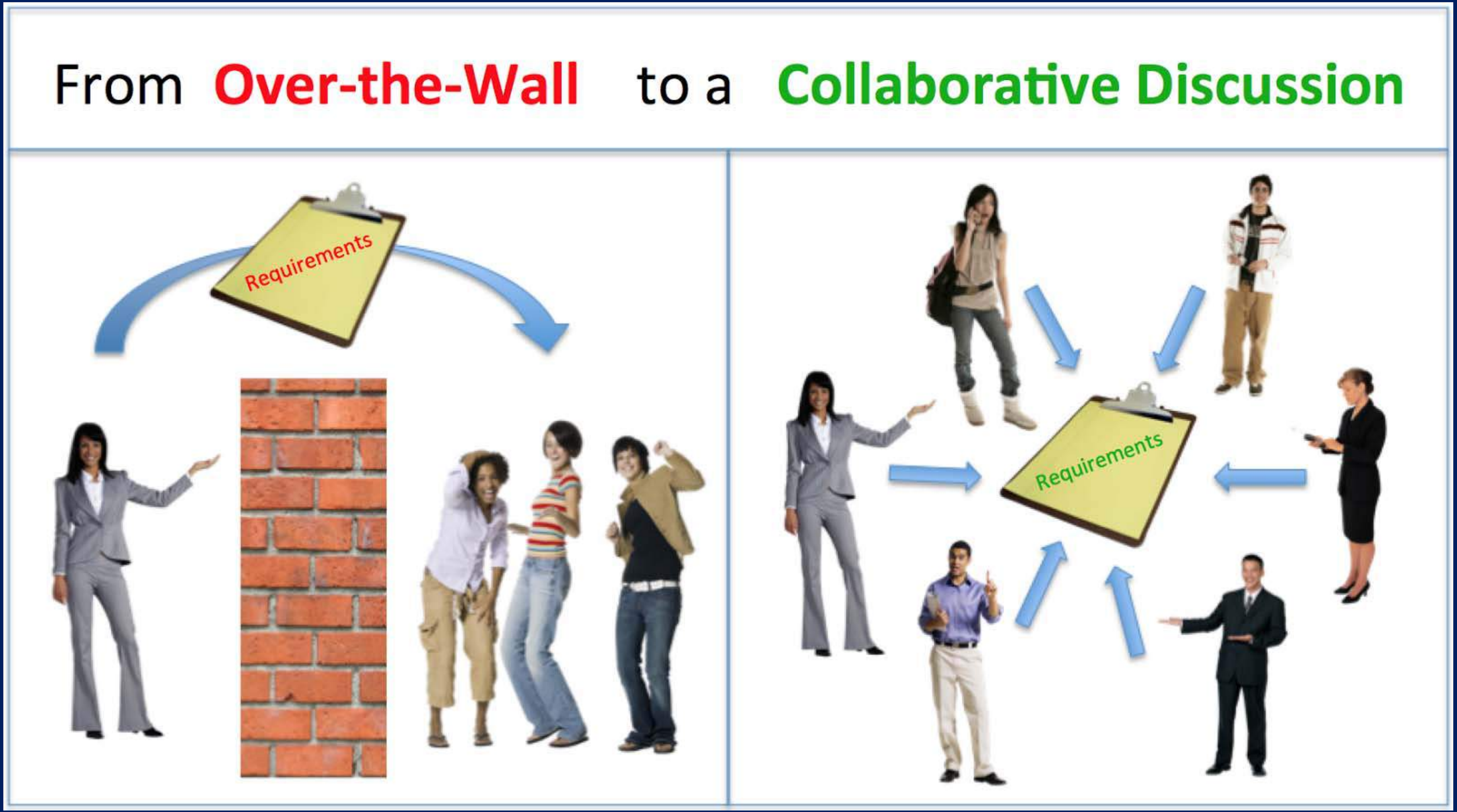
Design for Mfg. & Assembly:

- practice of designing products to reduce, and hopefully minimize, manufacturing and assembly difficulties and costs
- requires extensive knowledge of manufacturing and assembly processes

DFM Efforts

- Designer to understand the constraints imposed by manufacturing processes, and design products to minimize constraint violation
- Reorganization of product development using integrated product teams, concurrent engineering, and the like..
- Collections of DFM rules and practices
- Research in DFM methods, tools, and environments

Concurrent Engg.



From **Over-the-Wall** to a **Collaborative Discussion**

Design for Assembly

- Reduce
  - assembly time
  - cost
  - Difficulties
- How to?
  - minimize the number of parts
  - eliminate fasteners
- Benefits
  - fewer assembly operations
  - Low assembly costs

DFAM Concepts & Objectives

Design For Additive Manufacturing

- Objective of DFAM
  - Maximize product performance through the synthesis of shapes, sizes, hierarchical structures, and material compositions, subject to the capabilities of AM technologies.

Guidelines for Designing Products

- AM enables the usage of complex geometry in achieving design goals without incurring time or cost compared with simple geometry
- AM enables the usage of customized geometry and parts
- AM allows to consolidate parts, integrate features into more complex parts and avoid assembly issues
- AM allows designers to ignore all the constraints imposed by conventional manufacturing processes (although AM-specific constraints might be imposed)

Complex Geometry

- Geometric complexity of AM processes far exceeds that of conventional manufacturing processes
- Shapes of part cross sections can be arbitrarily complex, up to the resolution of the process
- SL and SLS processes can fabricate features almost as thin as their laser spot sizes.
- The need to remove the support structures necessary for some AM processes may also limit geometric complexity

Customized Geometry

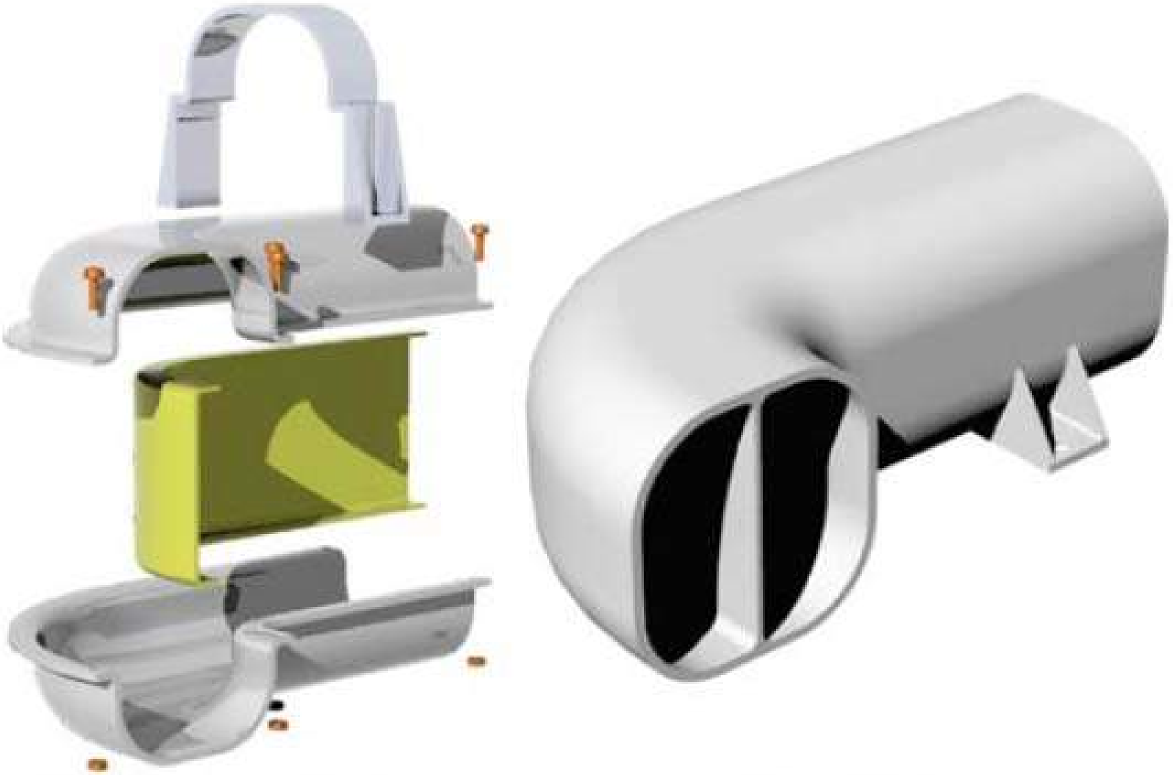
- AM processes can fabricate custom geometries.
- Example : hearing aid shells. Each shell must be customized for an individual’s particular ear canal geometry; helmet, shoes
- Hundreds of shells, each of a different geometry, can be built at the same time in a single machine
- Mass customization, instead of mass production

Customized Geometry

Integrated Assemblies

- Several parts can be replaced with a single, more complex part
- Ball-and-socket joint (relative motion), AM can build these components fully assembled
- Reduction in the number of assembly operations can greatly reduce production costs and assembly difficulties.
- Reduction in part count reduces product complexity from management and production perspectives.
- Fewer parts need to be tracked, sourced, inspected, etc.

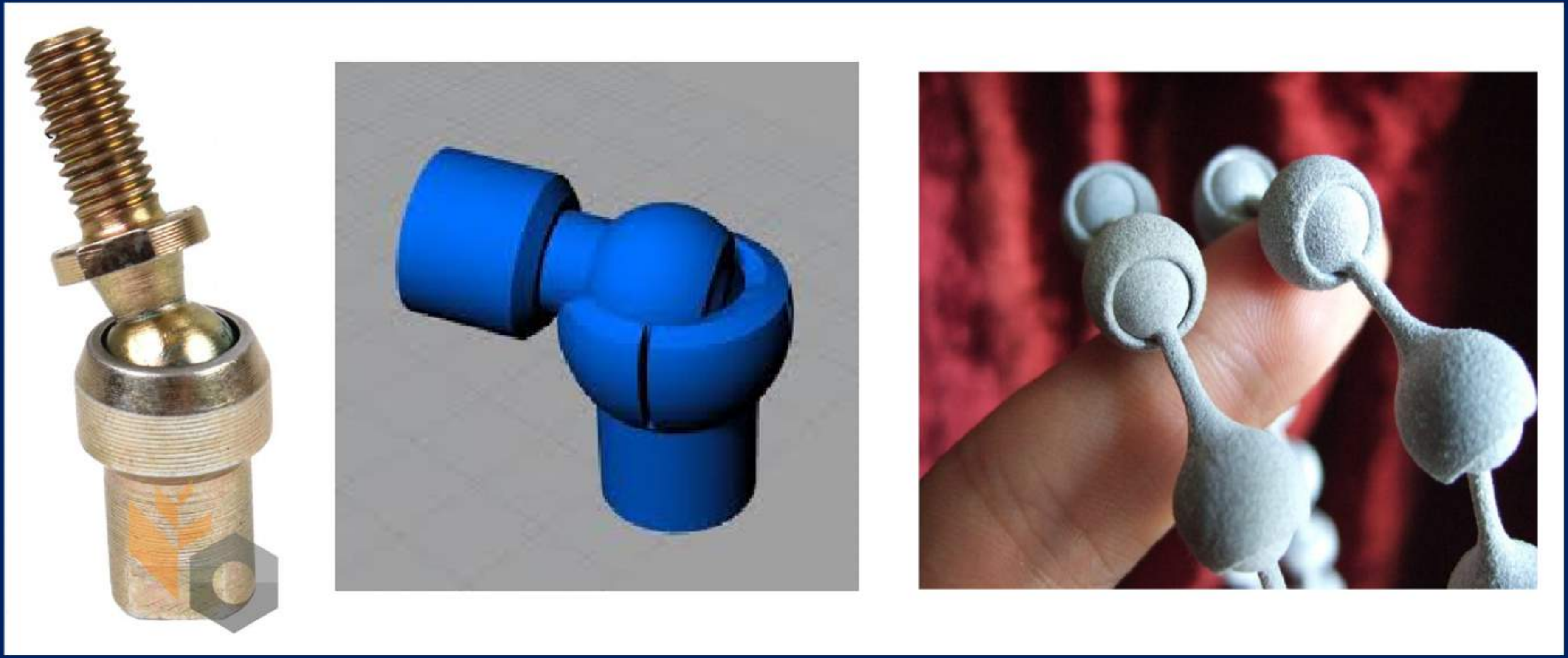
Integrated Assemblies



original design with 16 parts consolidated design

Aircraft duct

Integrated Assemblies



Elimination of Conventional DFM Constraints

- AM reduces the burden on organizations to have integrated product development teams that spend large amounts of time resolving constraints and conflicts
- Designers have to learn far fewer mfg. constraints
- Design constraints are no longer valid, and the designer can have much greater design freedom

AM Unique Capabilities

- Shape Complexity
- Hierarchical Complexity
- Functional Complexity
- Material Complexity

Shape Complexity

- Lasers in SLA and SLS processes can reach any point in a part’s cross section and process material there
- In machining, tool accessibility is a key limitation that governs part complexity.
- In injection molding, the need to separate mold pieces and eject parts greatly limits part complexity.
- Tremendously powerful for medical applications

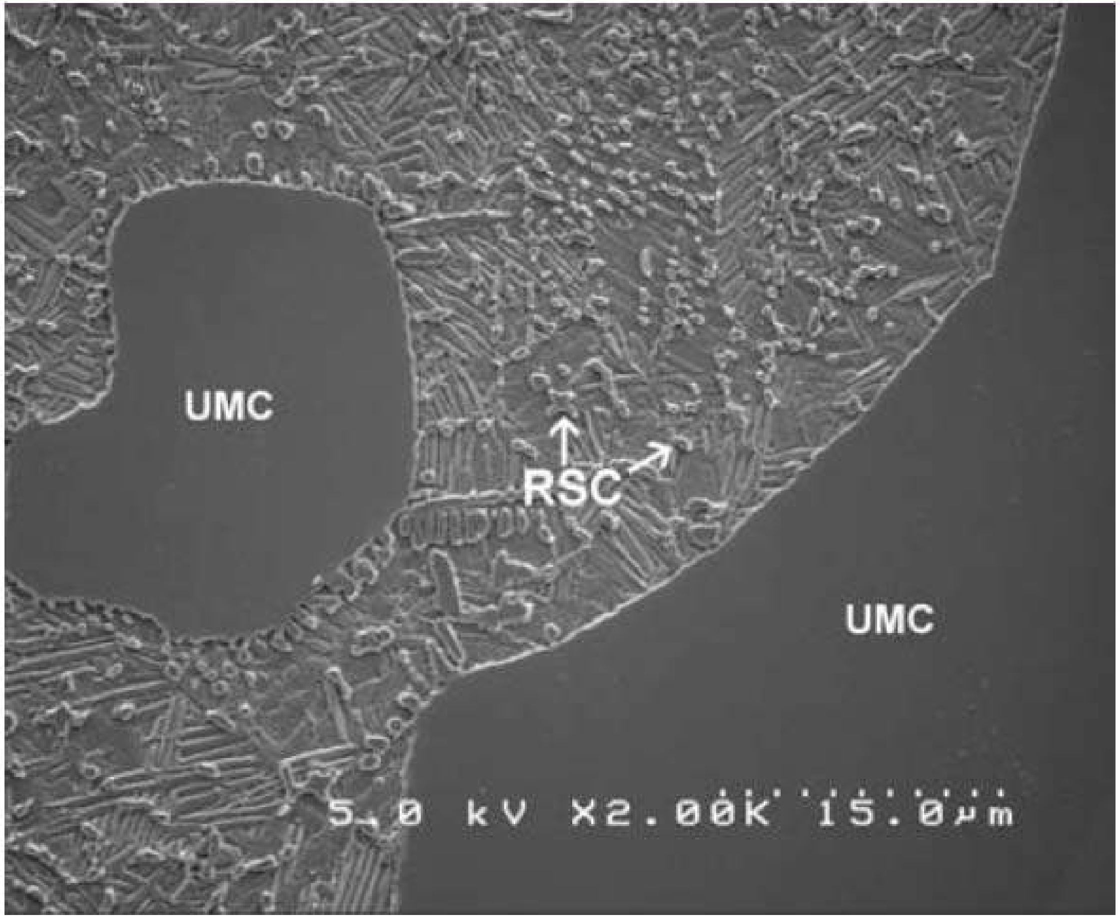
Hierarchical Complexity

- AM enables the design of hierarchical complexity

- In LENS, the nano/microstructure can be tailored in a particular location by controlling the size and cooling rate of the melt pool.

- the size and distribution of precipitates (nano-scale) and secondary particles (micro-scale), can be changed by locally modifying the laser power and scan rate.

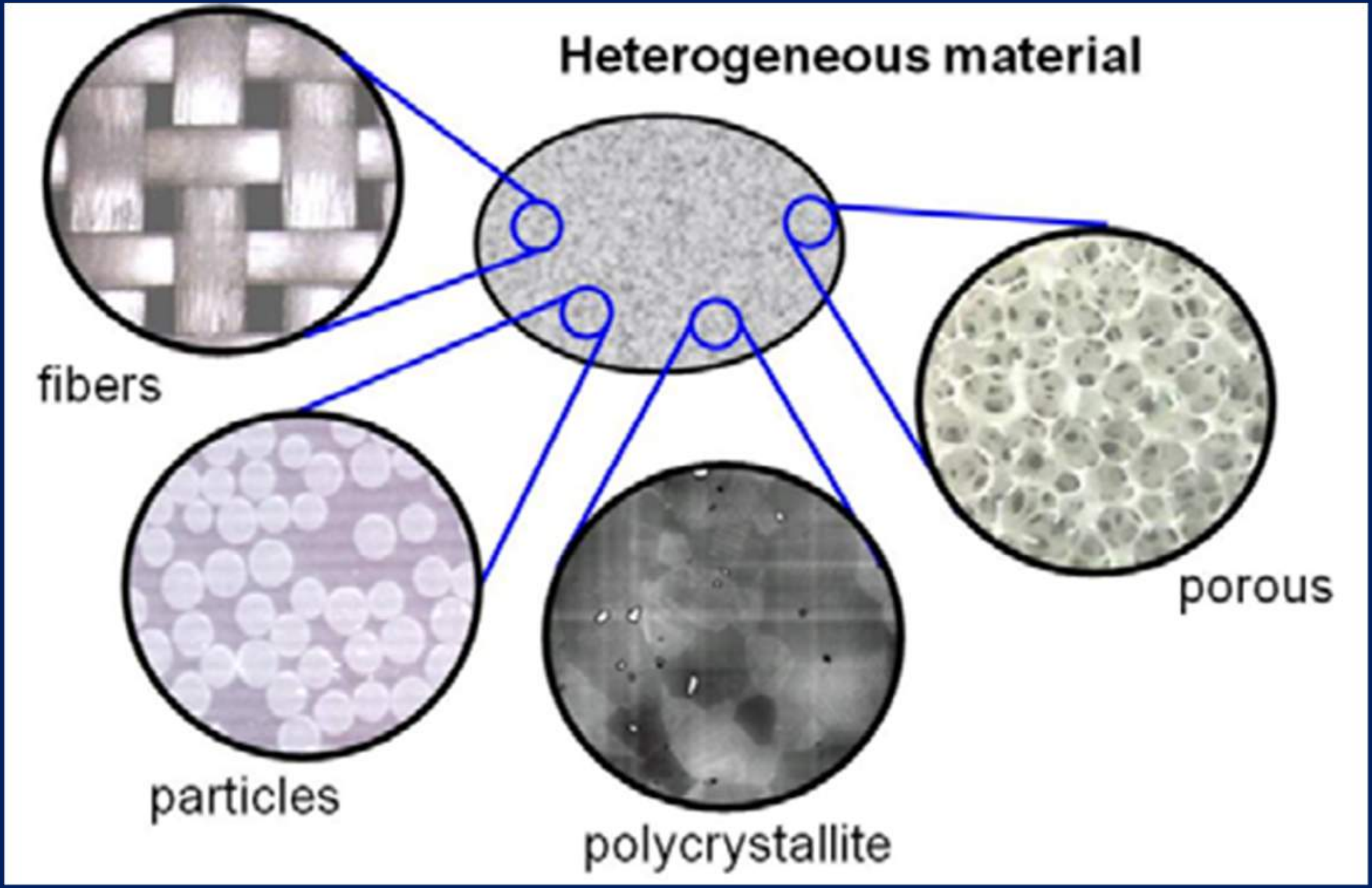
Hierarchical Complexity



60% CP-Ti, 40% TiC composite made using LENS.

The ratio of un-melted carbides (UMCs) to resolidified carbides (RSCs) within the Ti matrix is controlled by varying LENS process parameters

Hierarchical Complexity



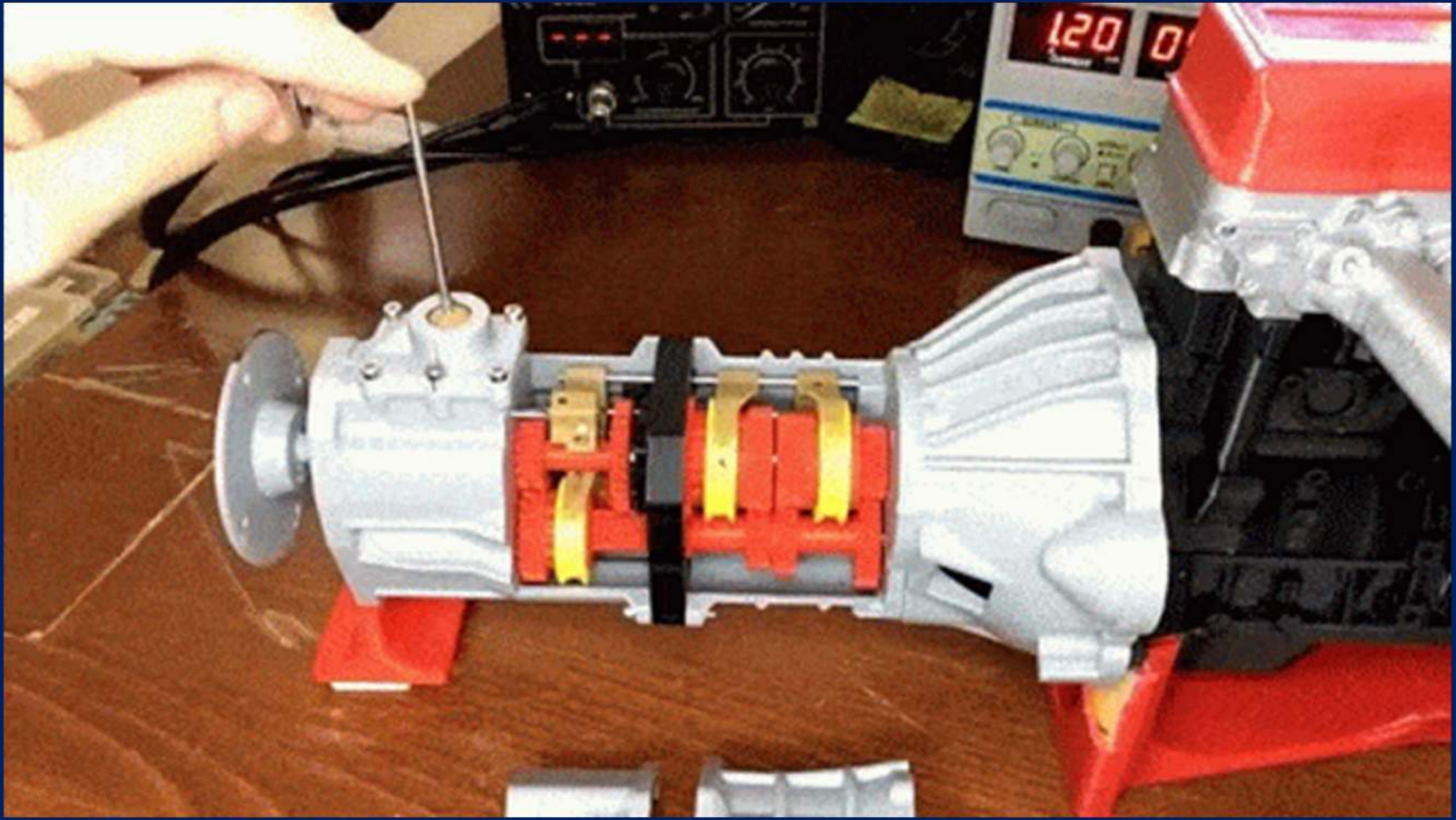
Functional Complexity

- In AM one always has access to the inside of the part.
- It is possible to fabricate operational mechanisms in some AM processes
- By ensuring that clearances between links are adequate, revolute or translational joints can be created.

Functional Complexity

Pulley-driven snake-like robot

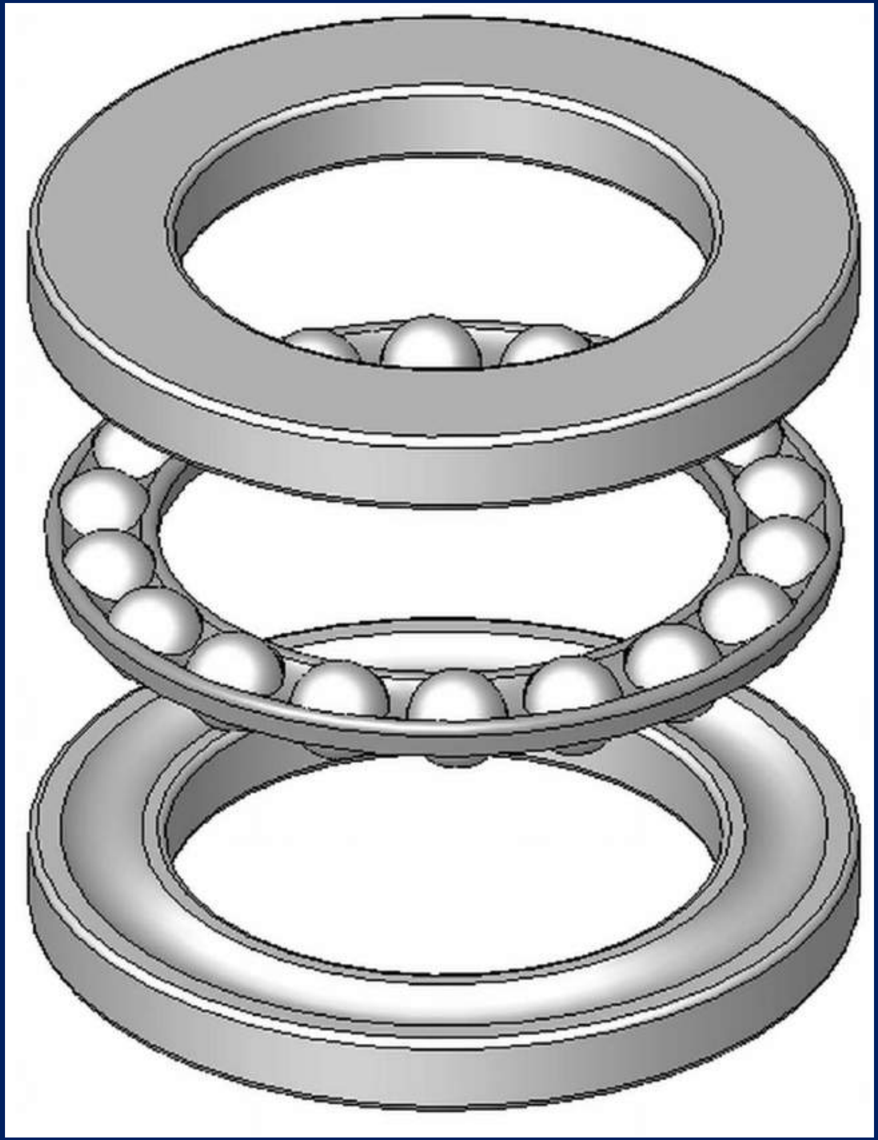
Functional Complexity

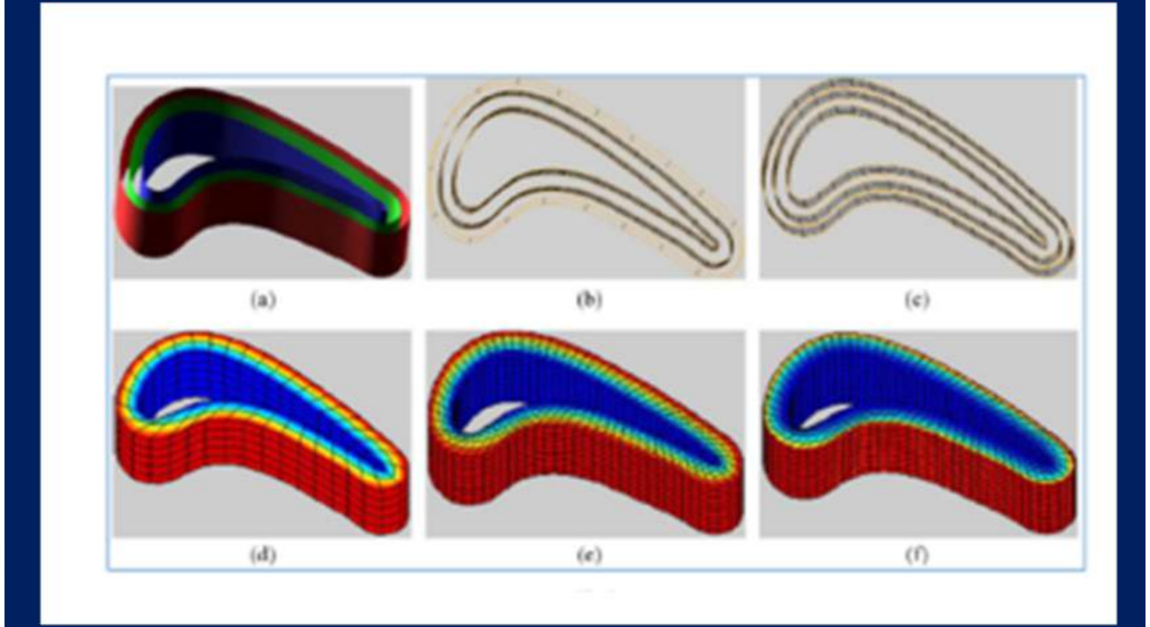


Material Complexity

- Different material properties in different regions of the part
- Functionally graded materials, or heterogeneous materials
- Change material composition gradually or abruptly during the build process
- LENS and DMD machines are capable of fabricating graded material compositions

Material Complexity





Exploring Design Freedoms

- Part Consolidation and Redesign
- Hierarchical Structures
- Industrial Design Applications

Design Tools for AM

- Current solid-modeling-based CAD systems have several limitations that make them less than ideal for taking advantage of the unique capabilities of AM machines

- CAD is a bottleneck in creating novel shapes and structures, in describing desired part properties, and in specifying material compositions

- Potentially, this issue will slow the adoption of AM technologies for use in production manufacture

Challenges for CAD

- Geometric complexity – need to support models with tens and hundreds of thousands of features

- Material compositions and distributions must be represented and must be physically meaningful

- Desired distributions of physical and mechanical properties must be represented and tested for their physical basis

Solid-Modeling CAD Systems

- CAD models can only provide geometric information for other applications, such as manufacturing or analysis, not complex multiple material information, which limits their usefulness.
- Without a high-fidelity representation of materials, it will not be possible to directly fabricate parts using emerging AM processes.
- CAD system capabilities must be developed that enable designers to synthesize a part, its material composition, and its manufacturing methods to meet specifications

Promising Technologies

- Implicit Modeling
- Multiscale Modeling
- Additional technologies can be combined to yield a CAD system that can be used to design components for a wide variety of purposes and with a wide variety of material compositions and geometric complexities.

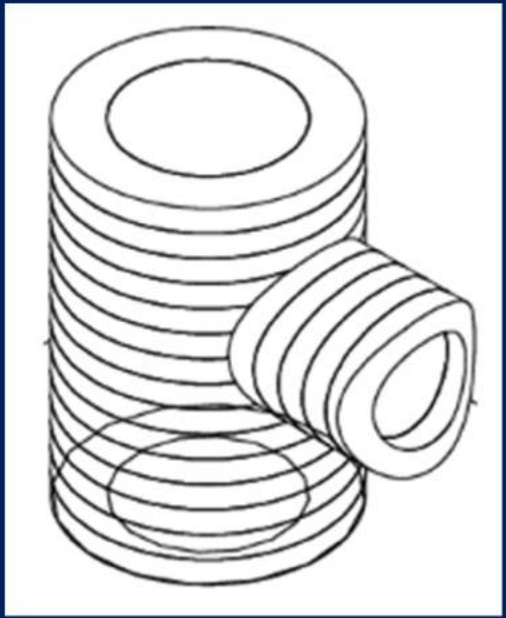
Design for AM

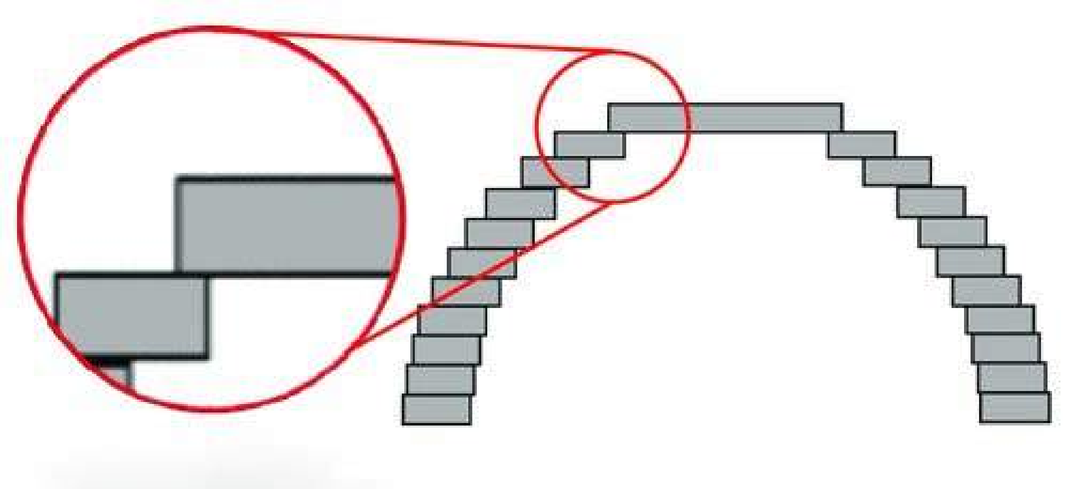
- Part Orientation
- Removal of Supports
- Hollowing Out Parts
- Inclusion of Undercuts & Mfg Constraining Features
- Interlocking Features
- Reduction of Part Count in an Assembly
- Identification Markings/Numbers

Part Orientation

- Orientation of the part within the machine can affect part accuracy
- When parts have complex features along multiple axes, there may not be an ideal orientation for a particular part
- Correct orientation may be a judgment
- Cylinder built on its end-vs-cylinder built on its side
- High aspect ratio parts may be better built lying down
- Will a certain orientation generate more supports?

Part Orientation





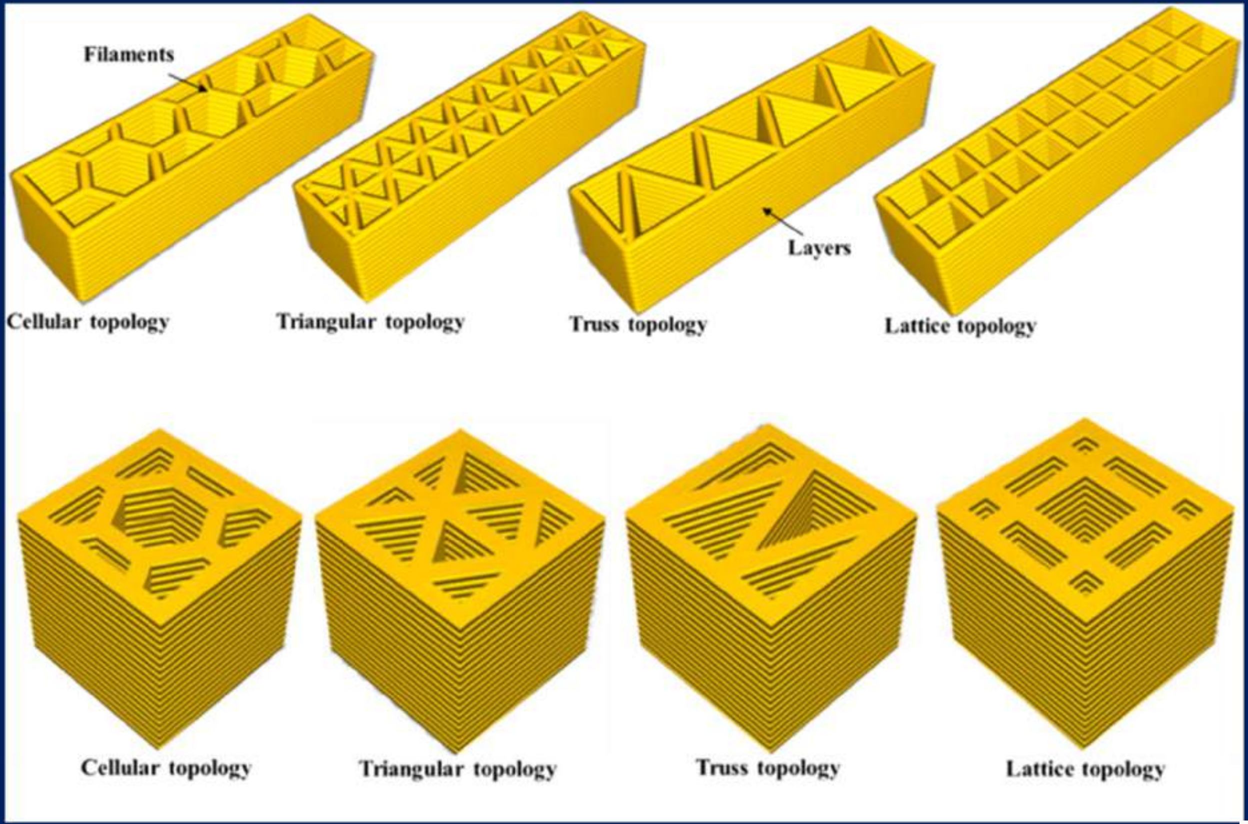
Removal of Supports

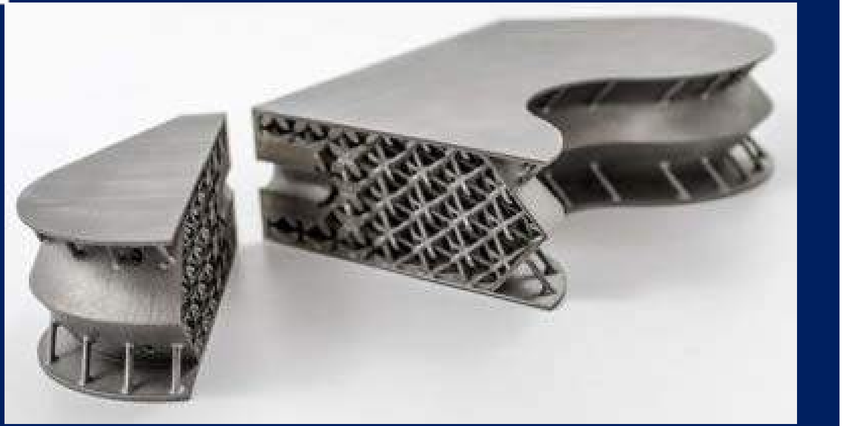
- Try and minimize Supports
- Parts that require supports may also require planning for their removal.
- Wherever the supports meet the part there will be small marks and reducing the amount of supports would make the part more accurate and reduce the amount of part cleanup and post-process finishing.
- A hollow cylinder with end caps built vertically will require supports for the top surface.
- SL parts may require drain holes for any trapped liquid resin

Hollowing Out Parts

- Parts that have thick walls may be designed to include hollow features if this doesn’t impede the final functionality.
- Reduced time to build the part
- Reduced cost from use of less material.
- Honeycomb- or truss-like internal structure can assist in providing support within the part.
- Additional time will take to design a part.
- Software systems will allow this to be done automatically.

Hollowing Out Parts

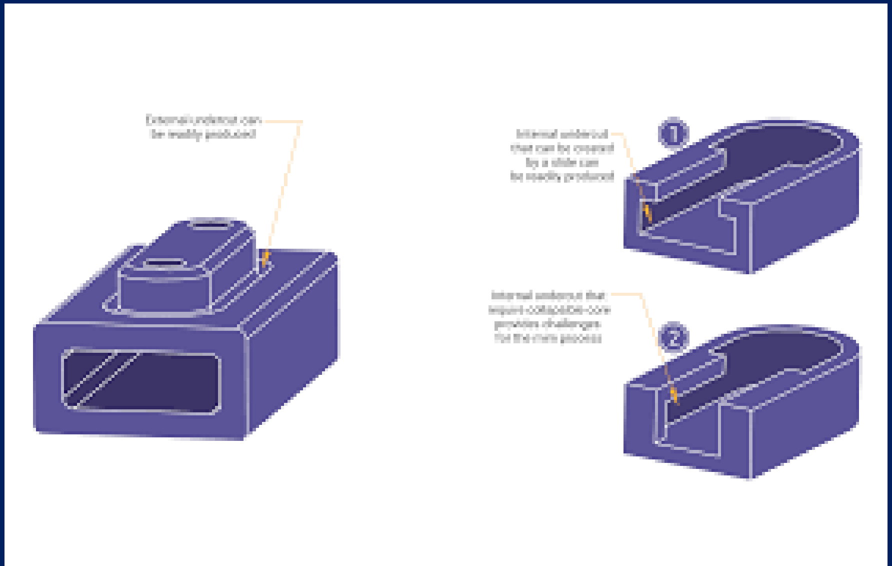


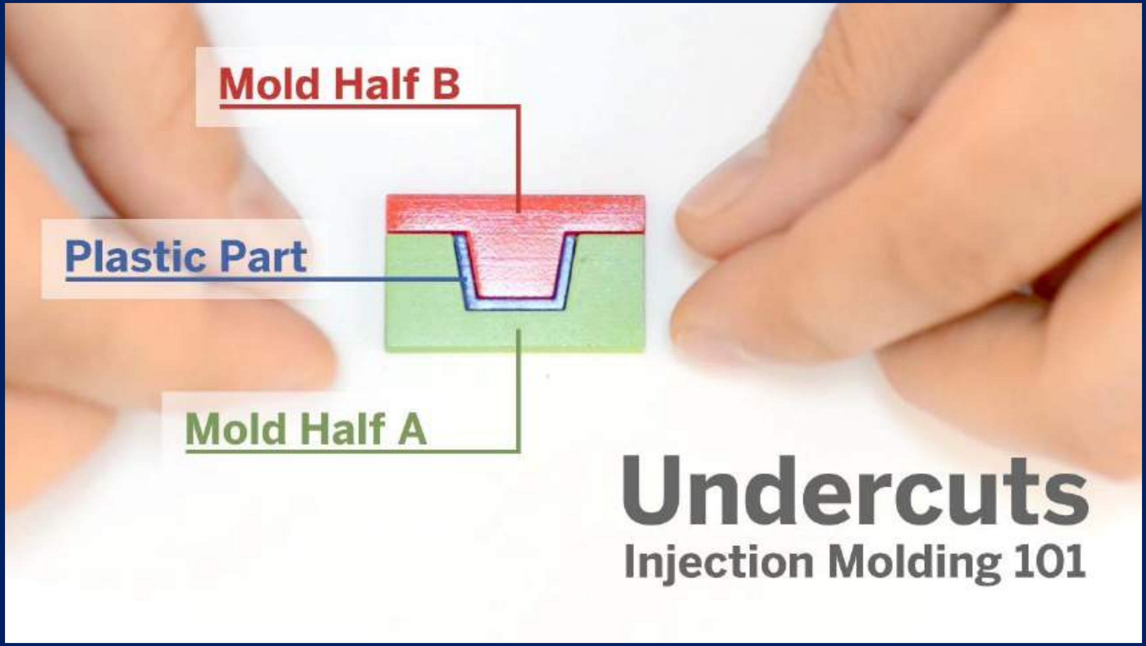


Inclusion of Undercuts

- When evaluating initial designs, focus may be on the esthetics or ultimate functionality of the part.
- Consideration of how to include manufacturing-related features would have lower priority at this stage.
- Undercuts, draft angles, holes, pockets, etc. must be created in a specific order when using multiple-stage processes.
- While this can be ignored when designing the part for additive processes, it is important not to forget them.

Undercuts


External undercut can
be readily produced
Internal undercut
that can be created
by a slide can
be readily produced
1
Internal undercut that
require collapsible core
provides challenges
for the mim process
2

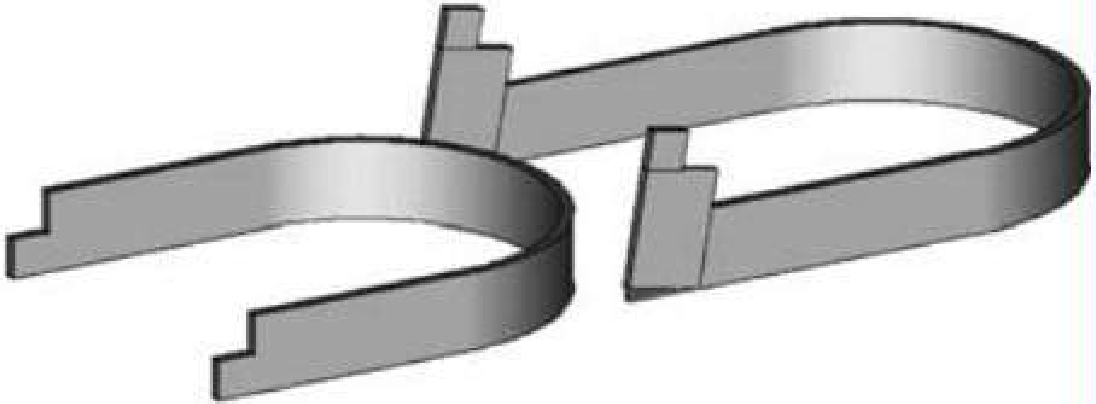

Mold Half B
Plastic Part
Mold Half A
Undercuts
Injection Molding 101

Interlocking Features

- AM has a finite build volume and large parts may not be capable of being built inside them.
- Solution: break the design into segments that can fit into the machine and manually assemble later.
- Regions where the breaks are made can be designed in such a way to facilitate reassembly
- Incorporate interlocking features and maximizing surface area so that adhesives can be most effective
- Breaking parts up may still be helpful even when they can still fit inside the machine.

Interlocking Features

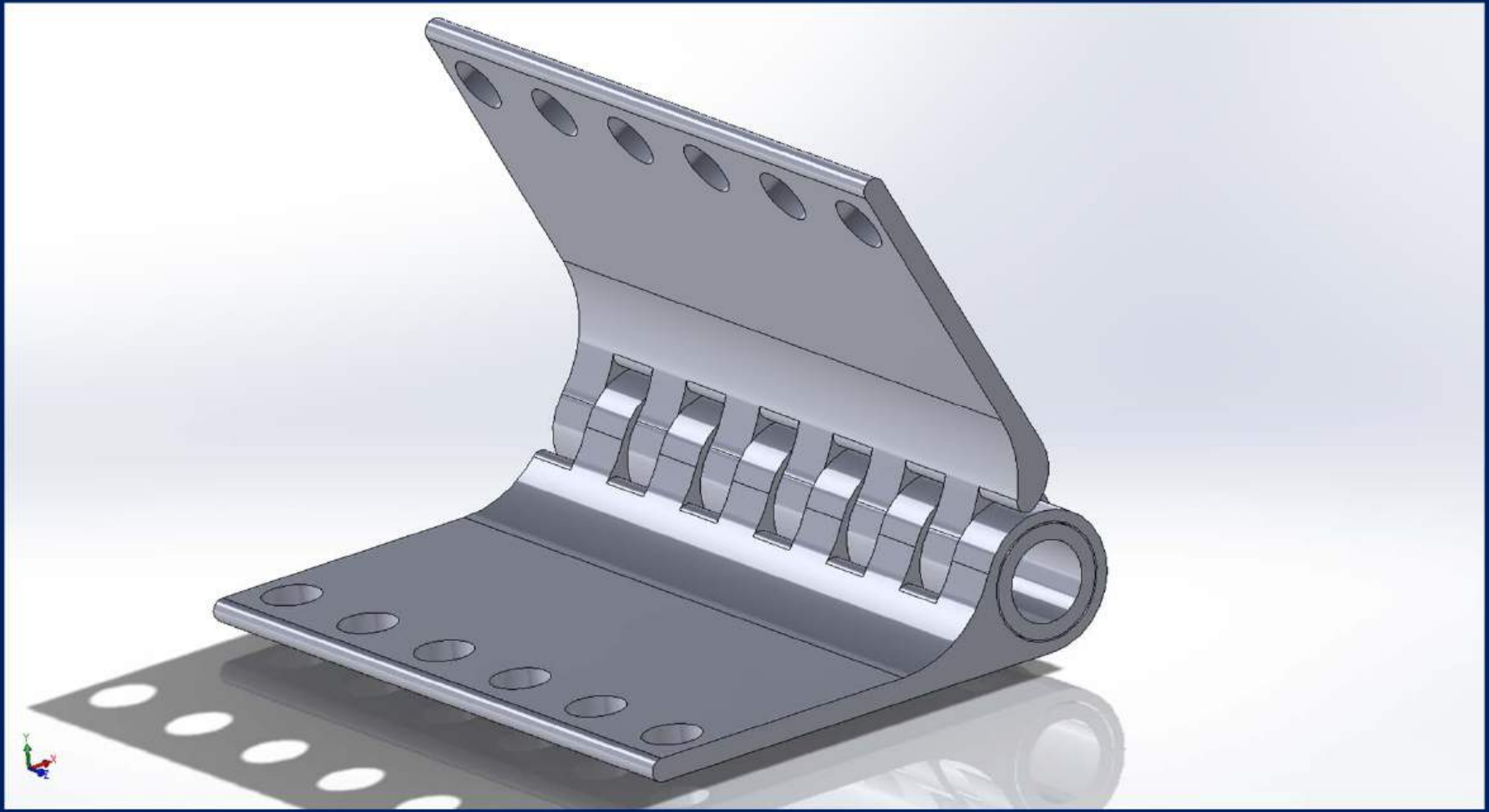
Intergrated Piece



2 Separate Pieces

Reduction of Part Count in Assembly

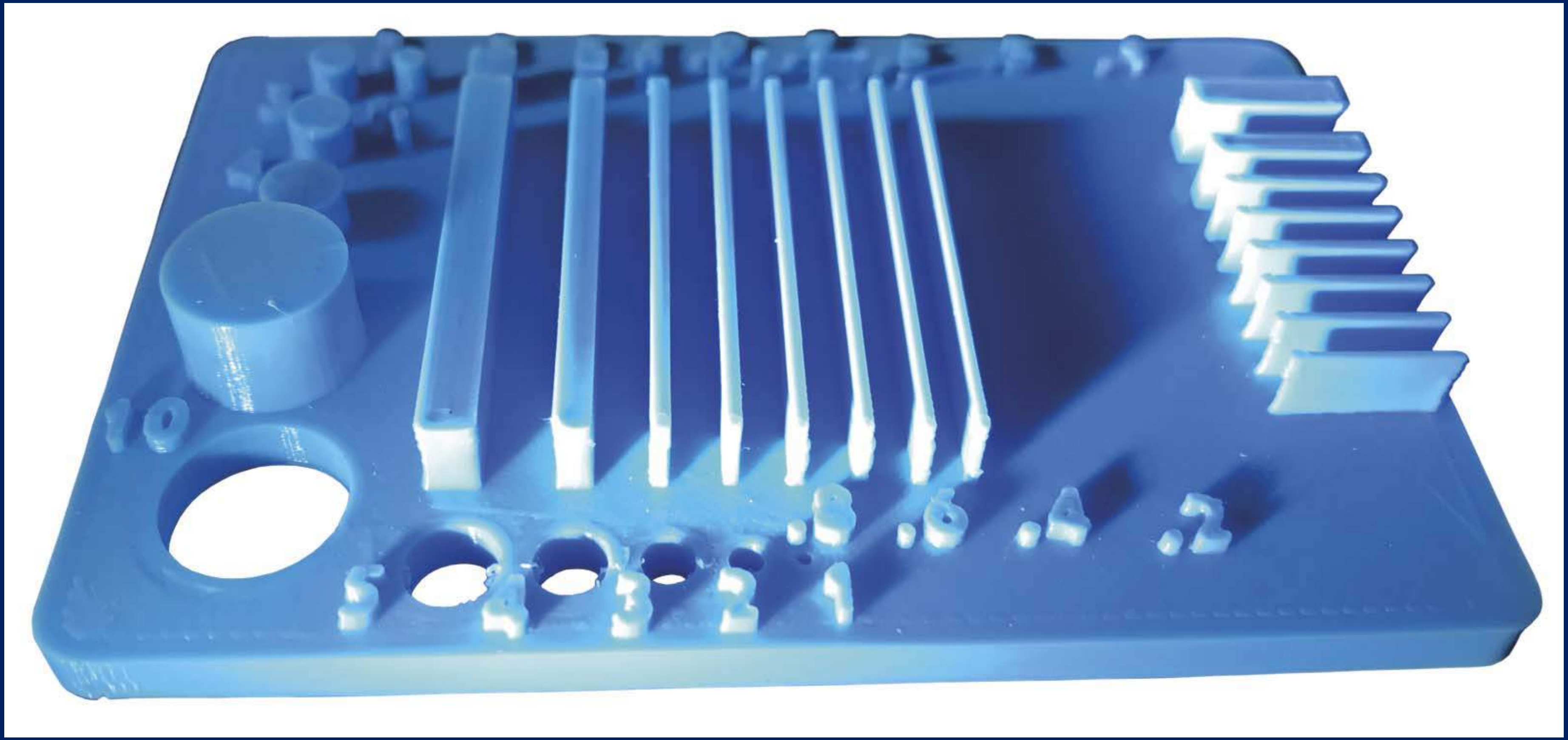
Simplify the part wherever possible by integrated assembly



Identification Markings/Numbers

- It may be difficult for a company to keep track of parts
- Include identifying features on the parts.
- This can be done when designing the CAD model but that may not be possible since the models may come from a third party.
- There are several software systems that provide tools for labeling parts by embossing alphanumeric characters onto them as 3D models.

Identification Markings/Numbers



Guidelines for Process Selection

- With the growth of AM, there is going to be increasing demand for software that supports making decisions regarding which machines to use and their capabilities and limitations for a specific part design.

Typical problems involving AM

- 1. Quotation support. Given a part, which machine and material should I use to build?
- 2. Capital investment support. Given a design and industrial profile, what is the best machine that I can buy to fulfill my requirements?
- 3. Process planning support. Given a part and a machine, how do I set it up to work in the most efficient manner alongside my other operations and existing tasks?

Selection Methods for a Part

- Decision Theory – three elements
  - Options – the items from which the decision maker is selecting
  - Expectations – of possible outcomes for each option
  - Preferences – how the decision maker values each outcome.
- Preferences model the importance assigned to outcomes by the decision maker.
- Example: a designer may prefer low cost and short turn-around times for a concept model, while being willing to accept poor surface finish.

Addressing selection problems

- Determining Feasibility
  - generate feasible alternatives: eg. materials and processes
- Selection
  - given those feasible alternatives, a quantification process is applied that results in a rank-ordered list of alternatives

Approaches to Determining Feasibility

- There are many possible applications for an AM part.
- Factors to be considered:
  - suitability of available materials
  - build cost and time
  - surface finish
  - accuracy requirements
  - part size
  - feature sizes
  - mechanical properties
  - resistance to chemicals
  - application-specific considerations.

Determining feasibility

- Deglin and Bernard developed a knowledge-based system - KADVISER platform which utilizes a relational database system with extensive material, machine, and application information

- A group at the National University of Singapore (NUS) developed an AM decision system that was integrated with a database system

Challenges of Selection

- Different AM systems focus on slightly different markets
- Expensive machines that can fabricate parts using a variety of materials with relatively good accuracy and/or material properties
- Cheaper systems, which are designed to have minimal setup and to produce parts of acceptable quality in a predictable and reliable manner
- Different users require different things from an AM machine

How to get Information

- Approach a manufacturer or distributor of AM equipment
  - May be biased towards their own product

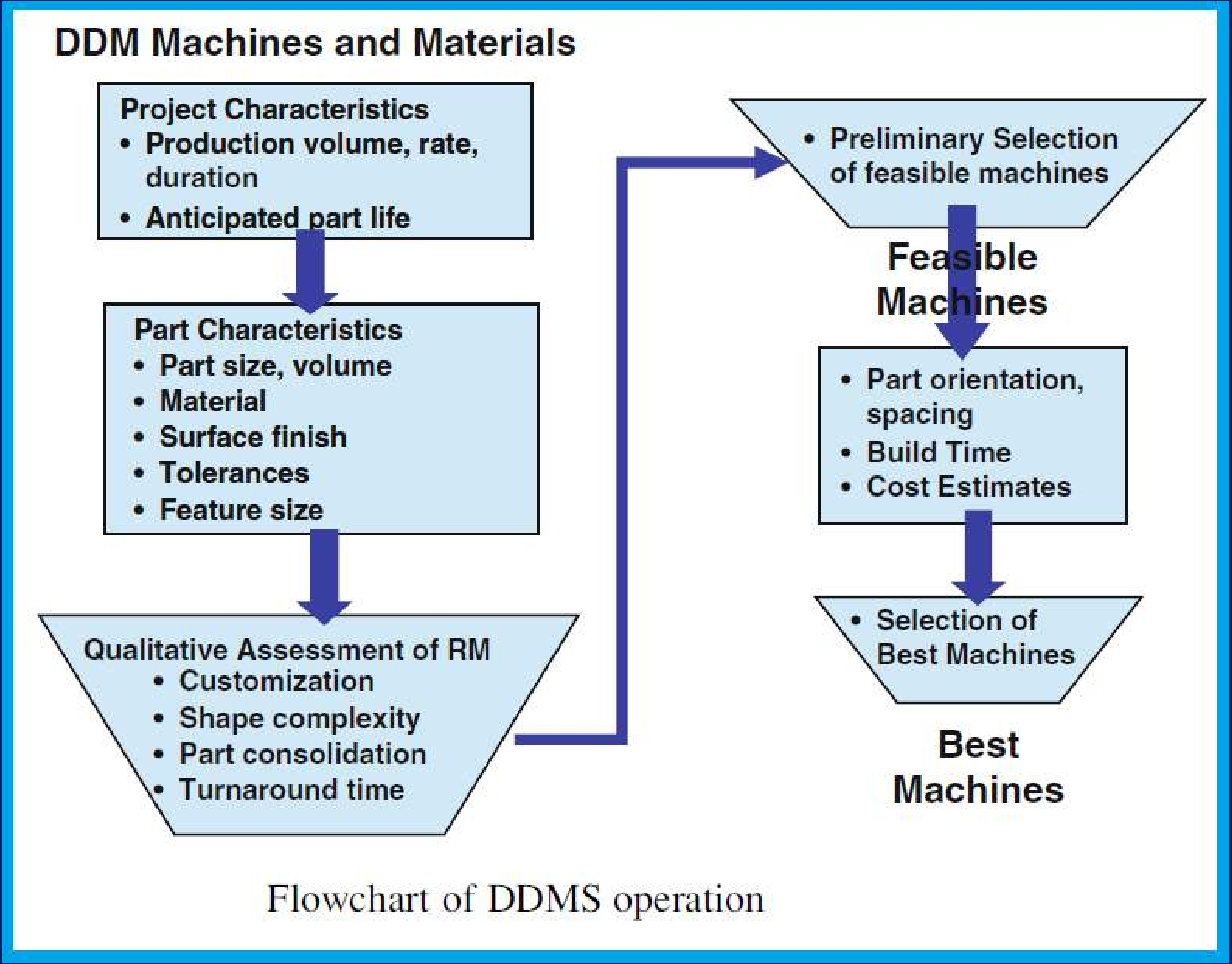
- Conventions and exhibitions are a good way to make comparisons

- Contact existing users
  - difficult and time consuming, but they can give very honest opinions

Example System for Preliminary Selection

- Software enables designers, managers, and service bureau personnel to:
  - Explore AM technologies for their application in a possible DDM project,
  - Identify candidate materials and processes,
  - Explore build times, build options, costs,
  - Explore manufacturing and life-cycle benefits of AM,
  - Select appropriate AM technologies for DDM applications.
  - Explore case studies, anticipate benefits
  - Support Quotation and Capital Investment decisions

Flowchart of DDMS operation



DDM Machines and Materials

Project Characteristics
- Production volume, rate, duration
- Anticipated part life

Part Characteristics
- Part size, volume
- Material
- Surface finish
- Tolerances
- Feature size

Qualitative Assessment of RM
- Customization
- Shape complexity
- Part consolidation
- Turnaround time

- Preliminary Selection of feasible machines

Feasible Machines

- Part orientation, spacing
- Build Time
- Cost Estimates

- Selection of Best Machines

Best Machines

Flowchart of DDMS operation

Production Planning and Control

Support for process planning ▶

- Activities of Service Bureaus (SBs), that operate one or more AM machines and processes.

- When any new part is presented to the process planner at the SB, it is likely that he has already committed to build several parts.

- Decision support software system may be useful in keeping track and optimizing machine utilization

Info Presented to the Process Planner

- Part geometry
- Number of parts
- Delivery schedule for batches of parts
- Processes other than AM to be carried out (pre-processing and post-processing)
- Expectations of the user (accuracy, degree of finish, etc.)

Areas to be Explored

- Production Planning
- Pre-processing
- Part Build
- Post-processing

Production Planning

- Suitable AM process & machine must be identified from among those in the facility
- AM machine availability must be considered
- If the SB has more than one suitable machine, a choice must be made as to which machine to use
- If the job is for a series of part batches, the SB may choose to run all batches on the same machine, or on multiple machines.
- A job scheduling system should be used, particularly for production manufacturing applications, so that part batches can be produced to meet deadlines

Pre-processing

- Software-based manipulation carried out on the file that describes the geometry of the part.

  - Modification of the design

  - Determination of build parameters.

Modification of the design

- Part details may need adjustment to accommodate process characteristics.
  - Example: shaft or pin diameters may need to be reduced, to increase clearance for assembly.

- Models may require repair if the STEP, IGES, or STL file has problems such as missing triangles, incorrectly oriented surfaces, or the like.

Build Parameters

- Selecting a part orientation
- Support generation
- Setting of build styles
- Layer thickness selection
- Temperature setting
- etc

Part Build

- In FDM or LENS, build time does not really matter whether parts are built one after another or parts are grouped together in batches.
- In SLS significant preparation time is taken before the build process takes place such as powder bed heating
- Part orientation can cause difficulties when organizing the batch production of parts
- Support structures give additional problem, both in terms of build time (allocation of time to build the support structures for different orientations) and post-processing time (removing the supports).

Post-Processing

- All AM parts require a degree of post-processing
- Low-end PP:
  - removal of support structures or excess powder for those who merely want quick, simple verification.
- High-end PP:
  - parts may require a large amount of skilled manual work in terms of surface preparation and coating
  - a complex rapid tooling process may require numerous manual and automated stages

Unit – 3 : Review

- DFAM concepts and objectives
- AM unique capabilities
- Exploring design freedoms
- Design for AM
- Guidelines for process selection

End of

Unit - 3

ME 18002

3D PRINTING AND DESIGN

Unit – 4

POST PROCESSING

POST PROCESSING

- Support material removal
- Surface texture improvement
- Accuracy improvement
- Aesthetic improvement
- Preparation for use as a pattern
- Property enhancements using non-thermal techniques
- Property enhancements using thermal techniques

Support Material Removal

- Material which surrounds the part as a naturally occurring by-product of the build process (natural supports)
- Rigid structures which are designed and built to support, restrain, or attach the part being built to a build platform (synthetic supports).

Natural Support Post-processing

- The part is fully encapsulated in the build material
- It must be removed from the surrounding material prior to its use
- Processes : primarily powder-based and sheet-based

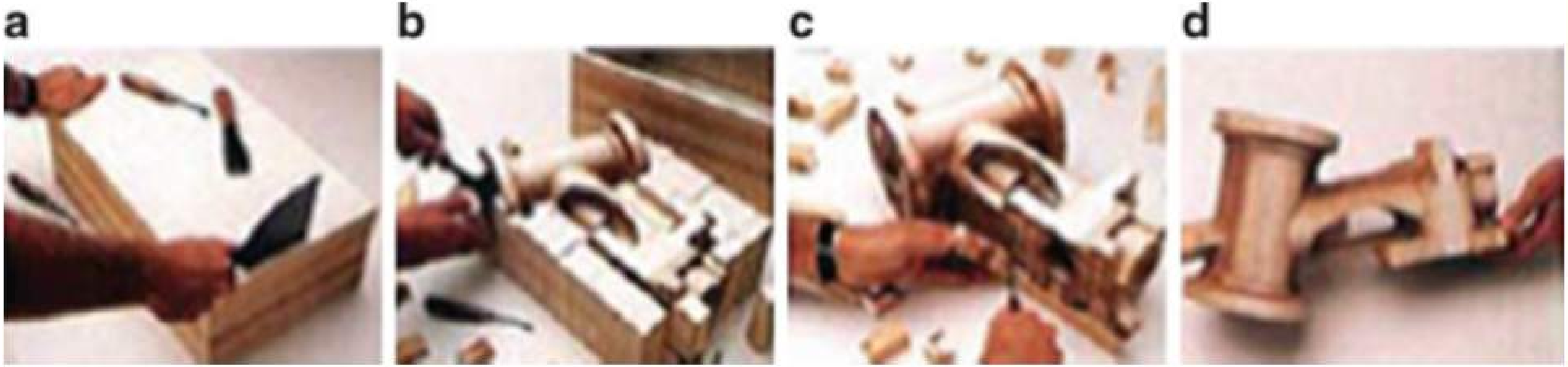
Support Removal - Powder-based

- The entire build (made up of loose powder and fused parts) is removed from the machine as a block
- Transported to a “breakout” station where the parts are removed manually from the surrounding powdered material.
- Loosely adhered powder - brushes, compressed air, and light bead blasting
- Powders sintered to the surface or entrapped in small channels or features - wood-working tools and dental cleaning tools

Support Removal - Powder-based…

Automated powder removal using vibratory and vacuum assist in a ZCorp 450 machine
(Courtesy Z Corporation)

Support Removal – Sheet Based



LOM support removal process (de-cubing)

(**a**) the finished block of material

(**b**) removal of cubes far from the part

(**c**) removal of cubes directly adjacent to the part

(**d**) the finished product

Photo provided by Cubic Technologies.

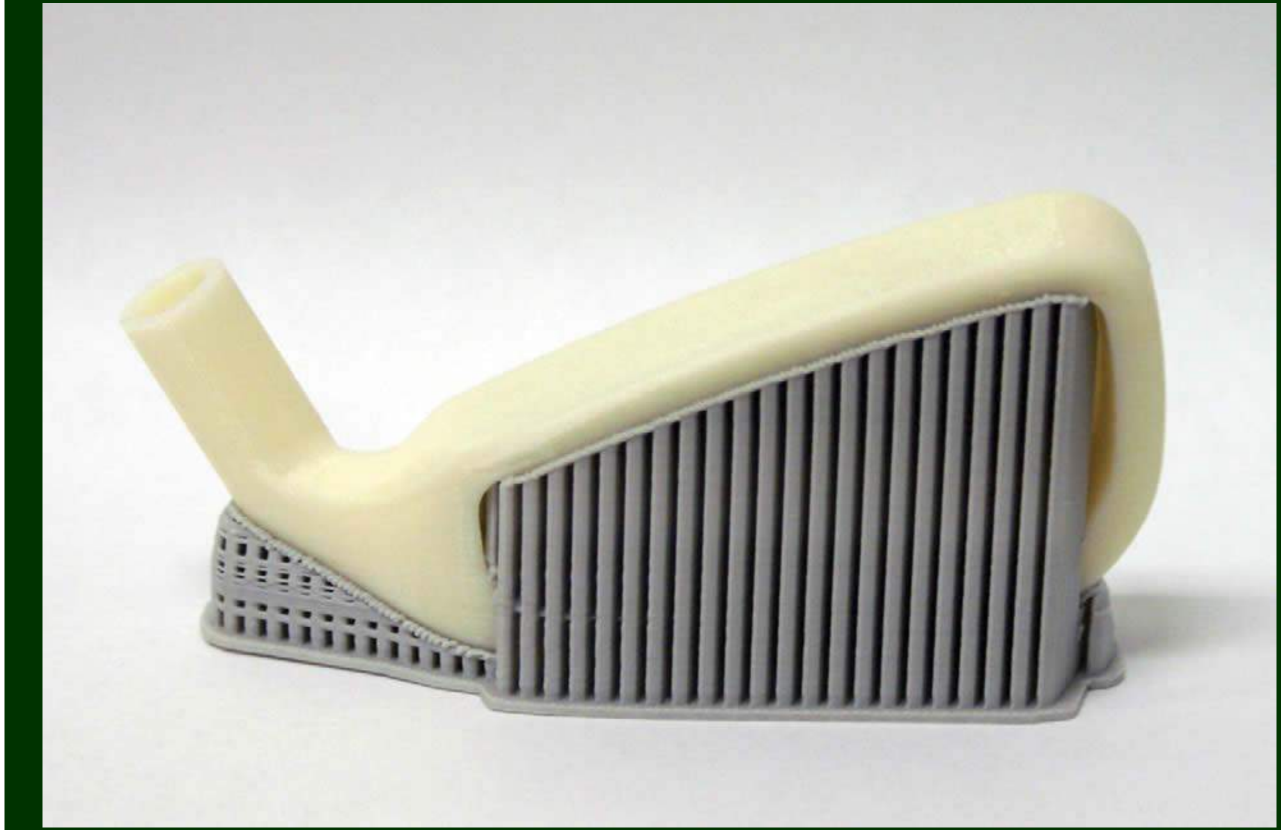
Synthetic Support Removal

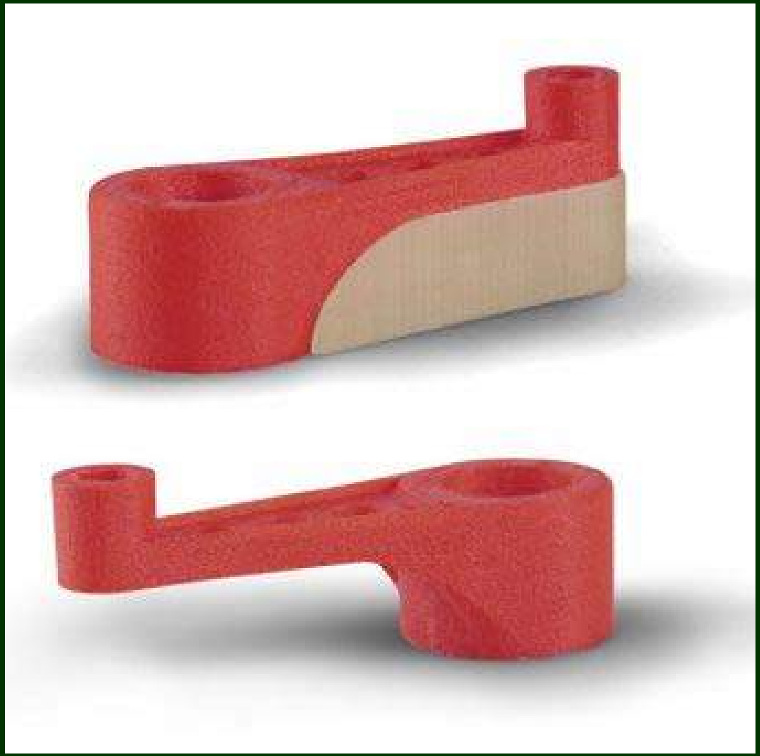
- Processes which do not naturally support parts require synthetic supports for overhanging features.
- Made from the build material or from a secondary material
- Secondary support materials simplify the removal as they are designed to be either weaker, soluble in a liquid solution, or to melt at a lower temperature than the build material

Supports Made from the Build Material

- Material extrusion (FDM), Material Jetting (MJ), and vat photopolymerization (SLA) processes
- The above processes use polymer parts; the low strength of the supports allows them to be removed manually.
- These supports are referred to as breakaway supports.

Support - FDM





Support - SLA

Support - Metal

- In dental framework, the metal supports are often too strong to be removed by hand;
  - milling
  - bandsaws
  - cut-off blades
  - wire-EDM
  - metal cutting

SLM dental framework

(© Emerald Group Publishing Limited)

Supports - Secondary Materials

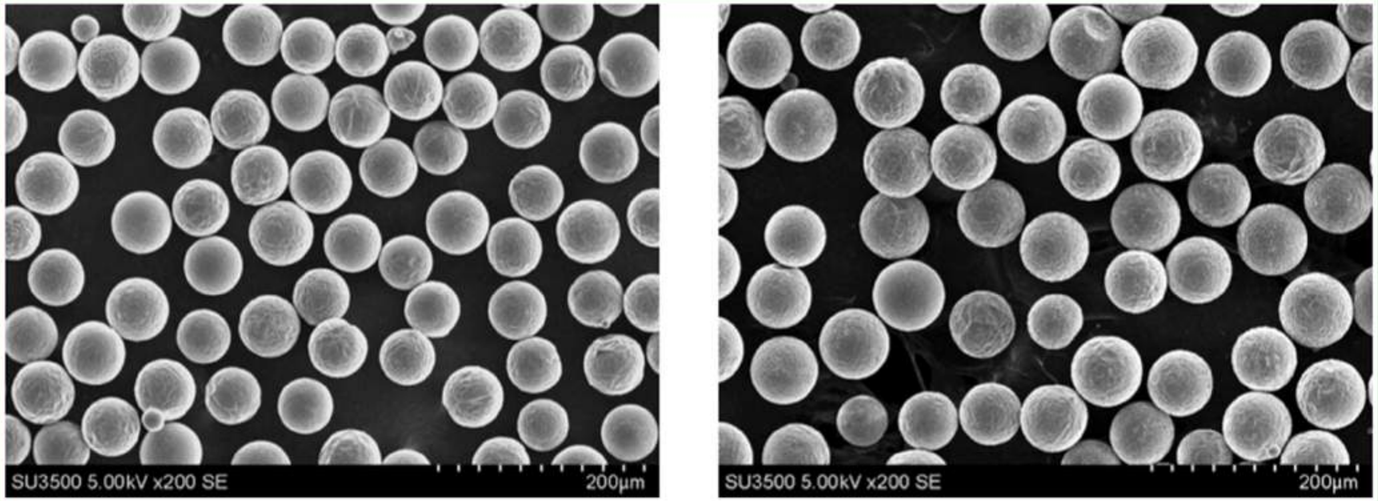
- To alleviate the labor-intensive manual removal of support materials
- Wax support materials: block of support/build is placed in a warm water bath; thus, melting or dissolving
- Polymer materials: can be melted and/or dissolved in a water-based solvent
- Metal Support: lower melting-temperature alloys or alloys which can be chemically dissolved in a solvent

Surface Texture Improvements

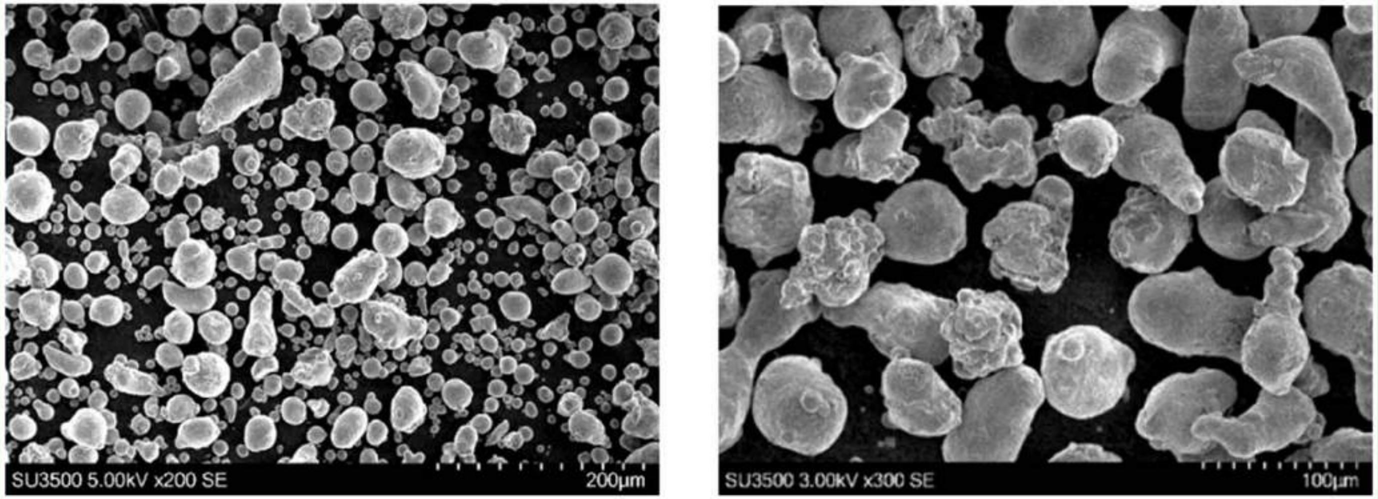
- Surface texture features are to be modified for aesthetic or performance reasons
- Common undesirable surface texture features:
  - ❖ stair-steps ⇒ : layer thickness
  - ❖ powder adhesion : powder morphology ⇒
  - ❖ fill patterns from material extrusion ⇒
  - ❖ witness marks from support material removal ⇒

Stair-Step

Powder Morphology

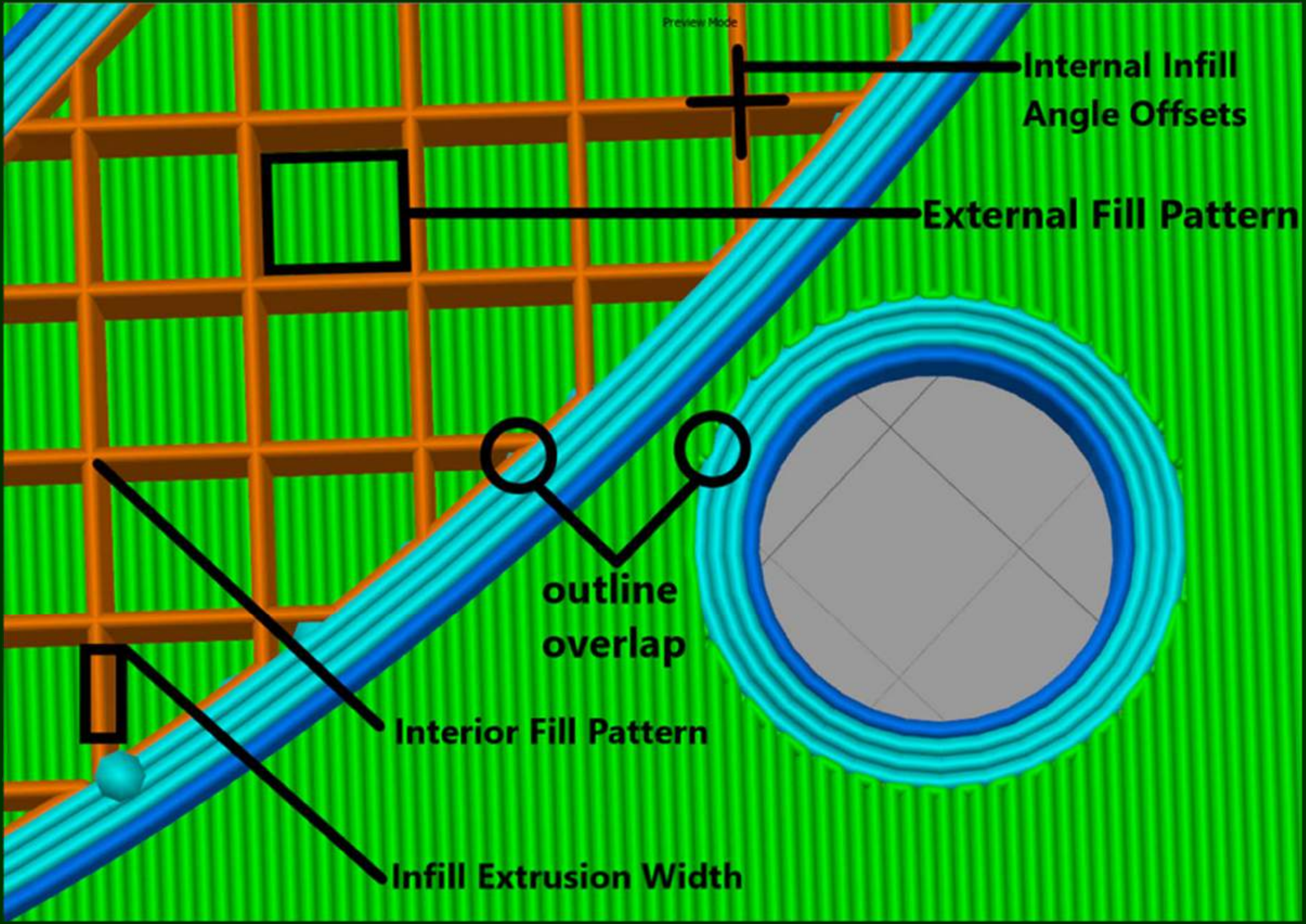


(a) Powder A (b) Powder B



(c) Powder C (d) Powder C Sieved

Fill Pattern



Witness Marks

Surface Finish

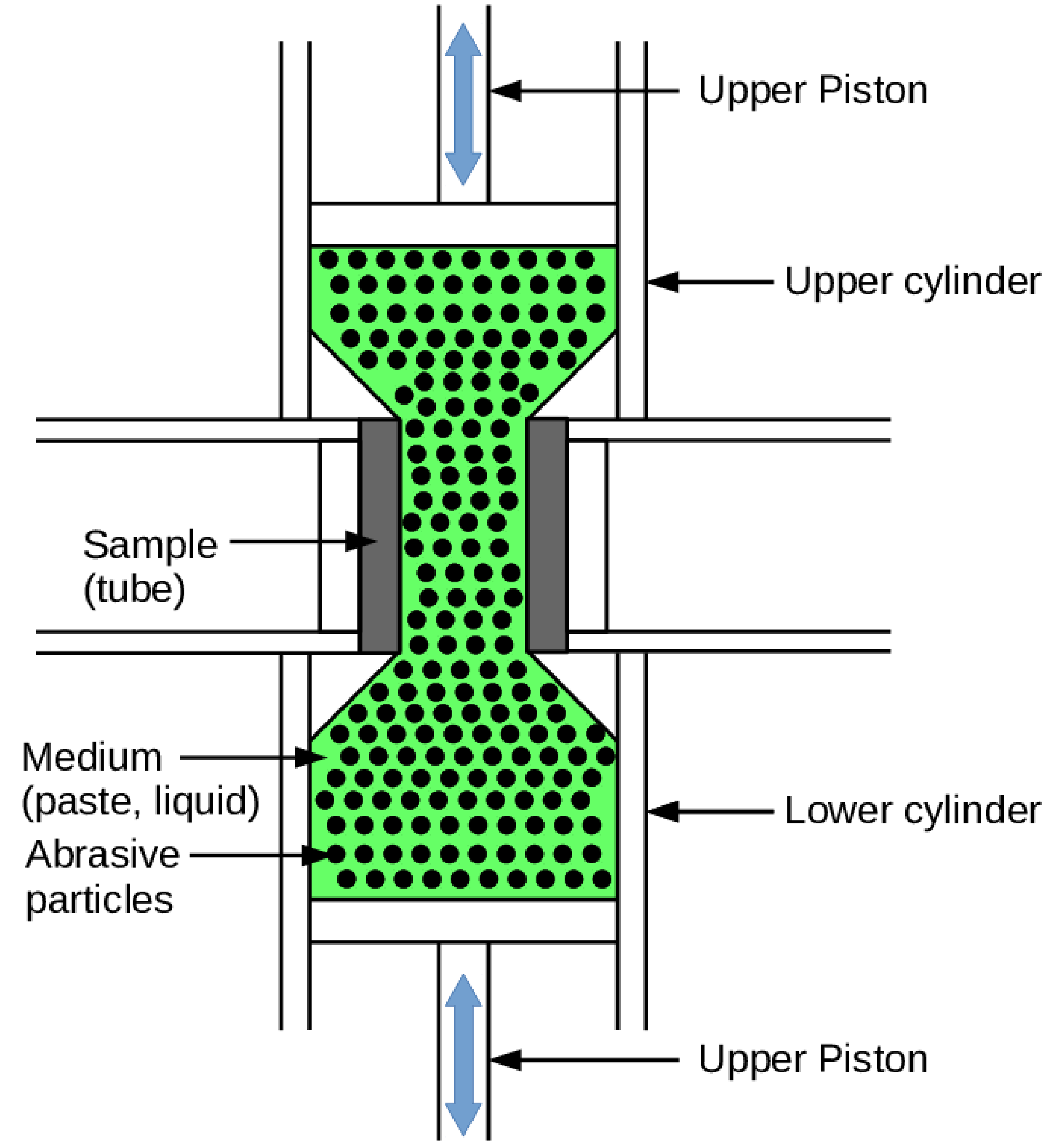
- Matte surface finish
  - simple bead blasting of the surface
    - evens the surface
    - removes sharp corners from stair-stepping
    - gives an overall matte appearance
- Smooth or polished finish
  - wet or dry sanding
  - hand-polishing

Surface Finish - Automated techniques

- Automated techniques
  - Tumbling – external features ➡
  - Abrasive flow machining - internal features ➡
- Drawbacks – compromise on
  - Small feature resolution
  - Sharp corner retention
  - Accuracy

Tumbling

Abrasive flow machining



Accuracy Improvements

- Wide range of accuracy capabilities : submicron tolerances to around 1 mm
- Larger build volume & faster build speed → poor accuracy

Sources of Inaccuracy

- Process-dependent errors
    - Positioning and indexing limitations of specific machine architectures
    - Lack of closed-loop process monitoring and control strategies
    - Volumetric rate of material addition (melt pool or droplet size)
- Material-dependent phenomena
    - Shrinkage
    - Residual stress-induced distortion

Model Pre-processing

- The position & orientation of part within the build chamber will influence part accuracy, surface finish, and build time
- Translation & rotation operations are applied to the CAD model to optimize the part position and orientation
- Shrinkage: a scale factor to be applied on STL model to compensate for the average shrinkage of the process chain.
    - some features may shrink slightly more or less than the average
    - using the largest shrinkage value is not an acceptable solution

Model Pre-processing…

- In order to make sure that there is enough material left on the surface to be machined, adding “skin” to the original model is necessary. This is referred to as making the part “steel-safe.”
- Compensating for shrinkage variation requires offsetting of the original model to guarantee that even the features with the largest shrinkage levels and all channels and holes are steel-safe

Methods for adding a skin

- Offset the surfaces and then recalculate all the surface intersections
- An algorithm is developed for offsetting all the individual vertices of an STL file by using the normal vector information for the connected triangles, then reconstructing the triangles by using new vertex values

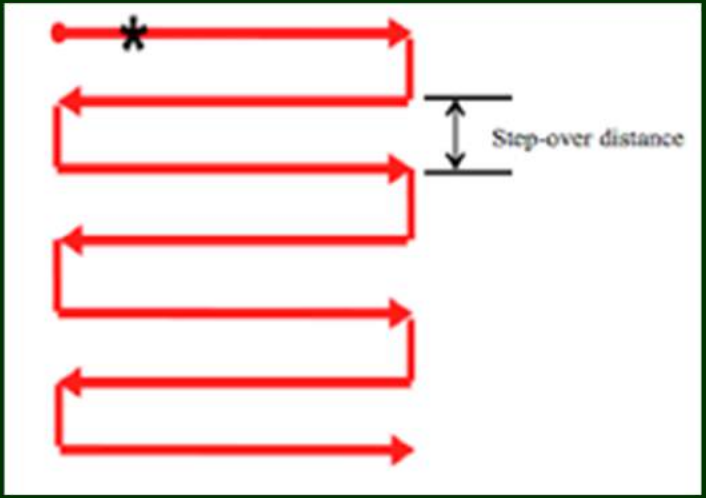
Machining Strategy (MS)

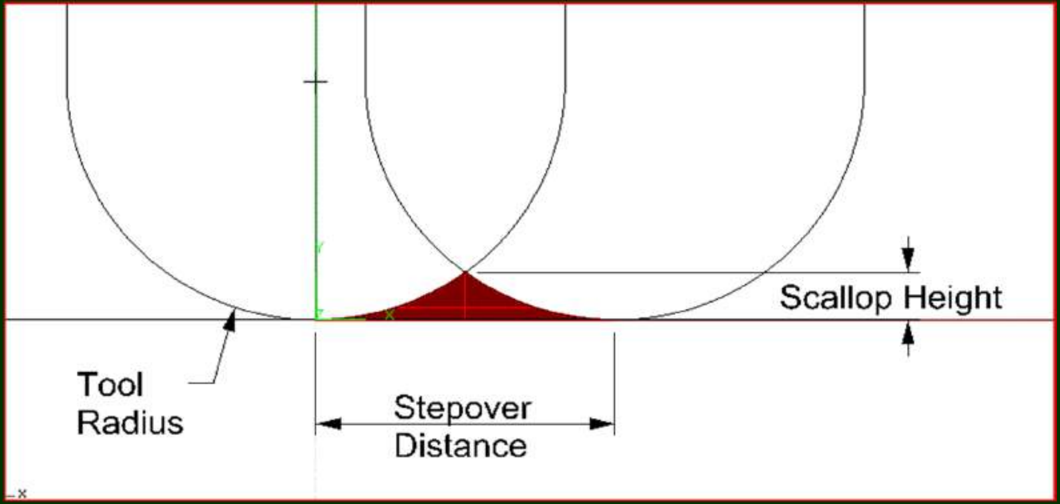
- MS is very important for finishing AM parts and tools
  - adaptive raster milling of the surface
  - hole drilling &
  - sharp edge contour machining can fulfill the needs of most parts.

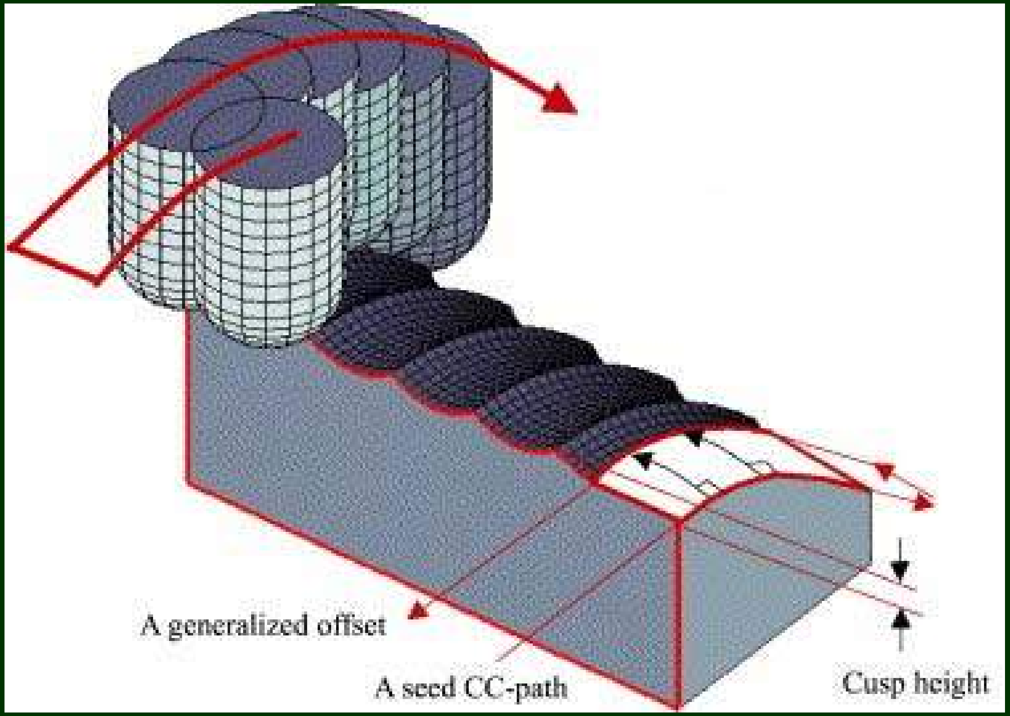
Adaptive Raster Milling

- When Raster Machining is used for milling operations, **stepover distance** between adjacent toolpaths is a very important parameter that controls the machining accuracy and surface quality ⇨
- Higher accuracy and surface quality require a smaller stepover distance
- The cusp height of material left after the model is machined is used as a measurement of the surface quality
- Adaptive stepover distance

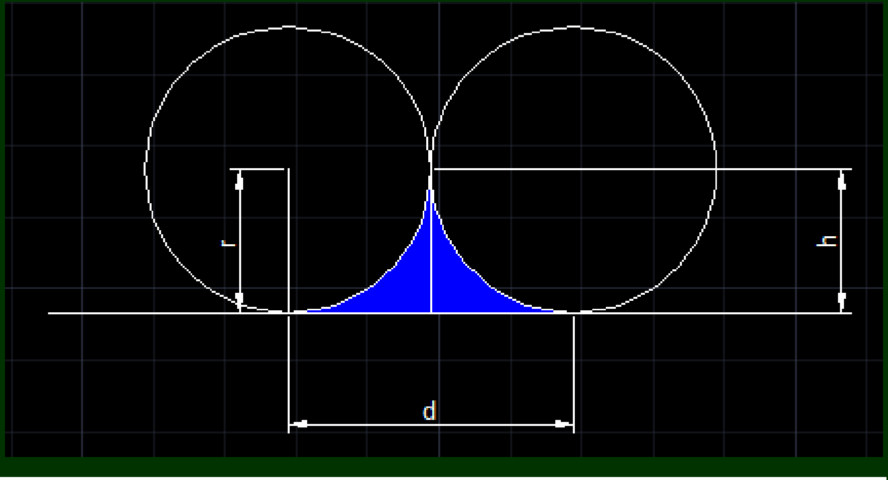
Stepover Distance



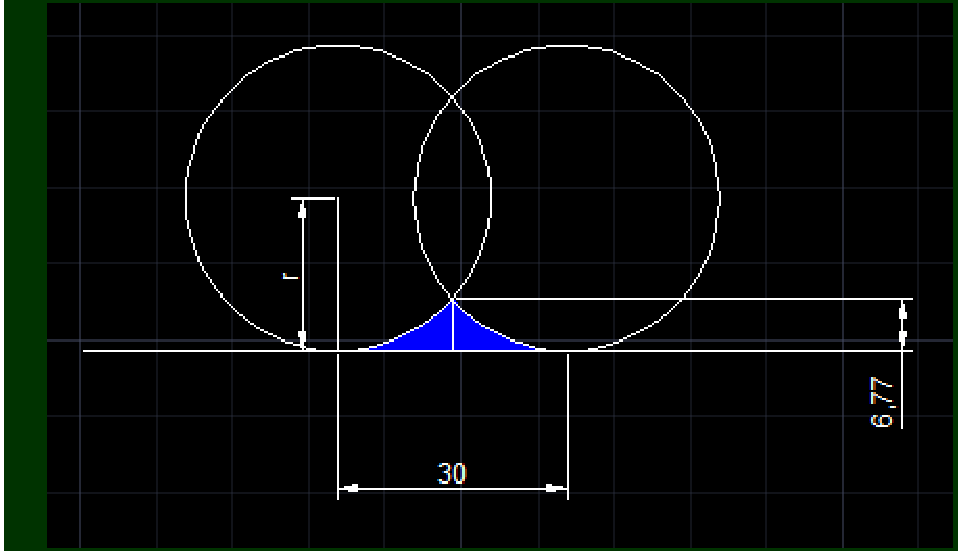


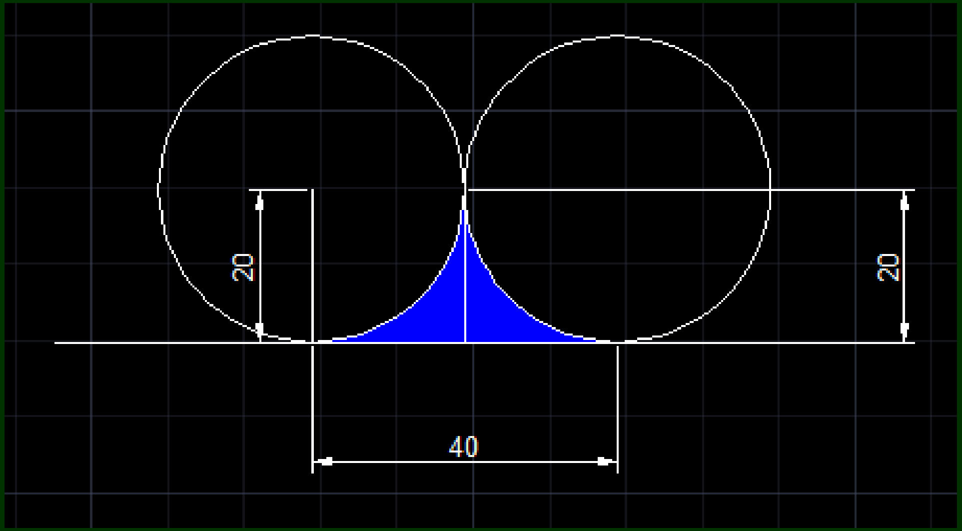


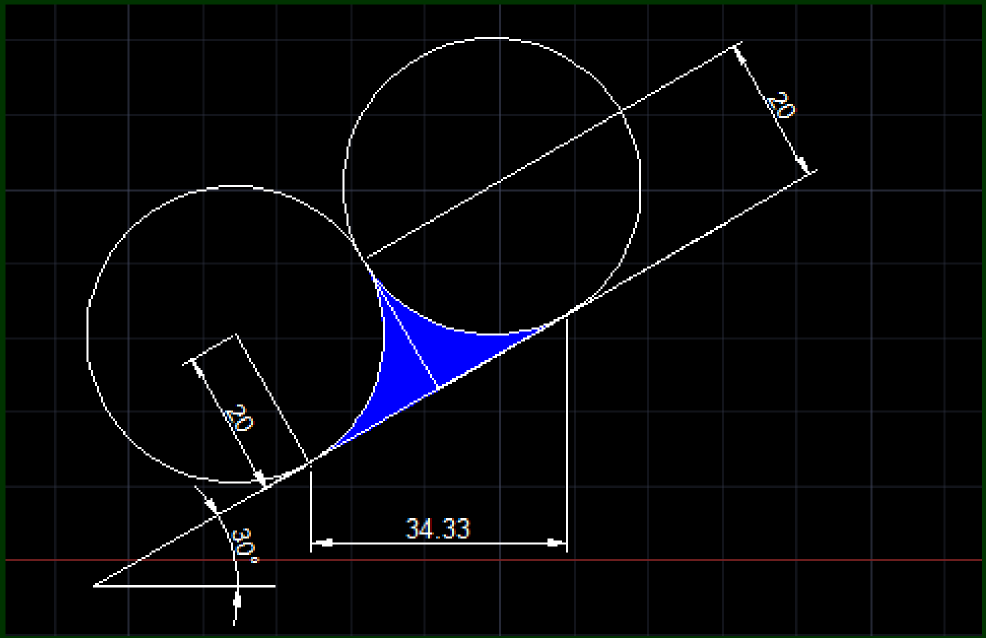
Stepover Distance



$$d = 2.0\sqrt{r^2 - (r-h)^2}\cos\alpha$$





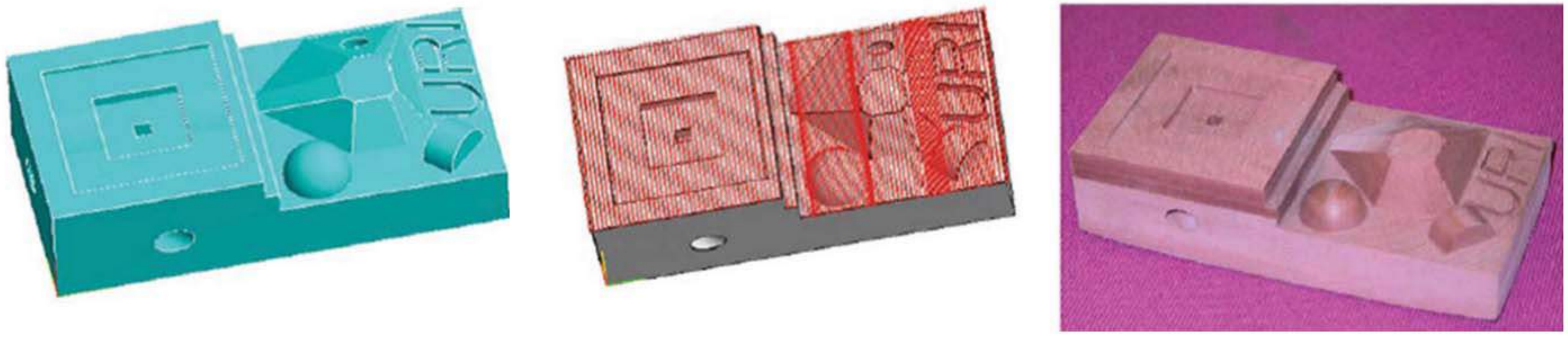


Stepover Distance…

$$d = 2.0\sqrt{r^2 - (r - h)^2}\cos\alpha$$

- Cutter radius (r)= 20 mm
- Cusp height (h) = 2 mm
- Angle (α) = 30 °
- Calculate step over distance (d).
- d = ?

Adaptive Raster Milling



CAD Model

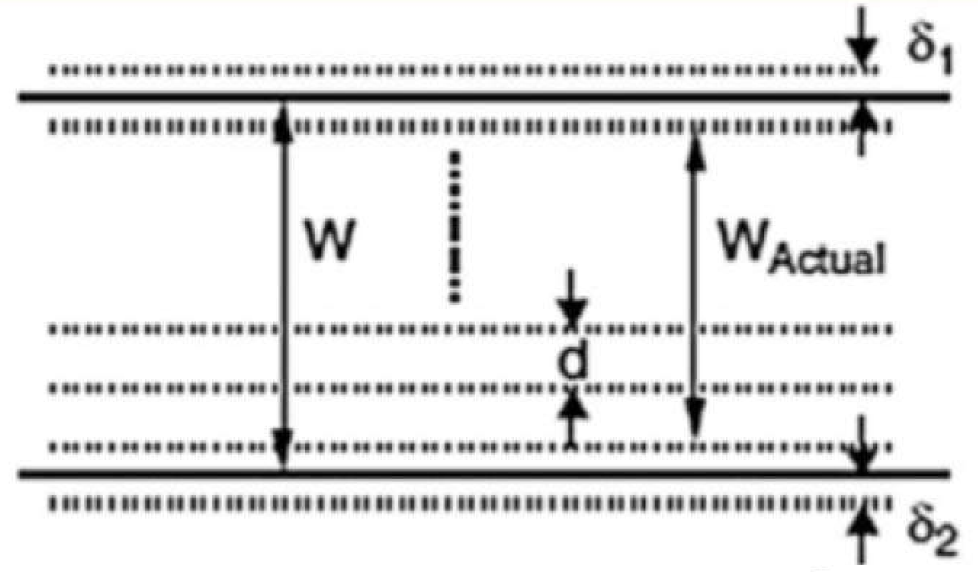
Tool Paths

Machined Part

Sharp Edge Contour Machining

- Sharp edges are often the intersection curves between features and surfaces. ⇒
- Normally, these edges define the critical dimensions.
- When using raster milling, the edges parallel to the milling direction can be missed, causing large errors.

Sharp Edge Contour Machining…



Influence of stepover distance on dimensional accuracy

- If a stepover distance *d* is used to machine a part with slot width *W* the slot width error will be at least:

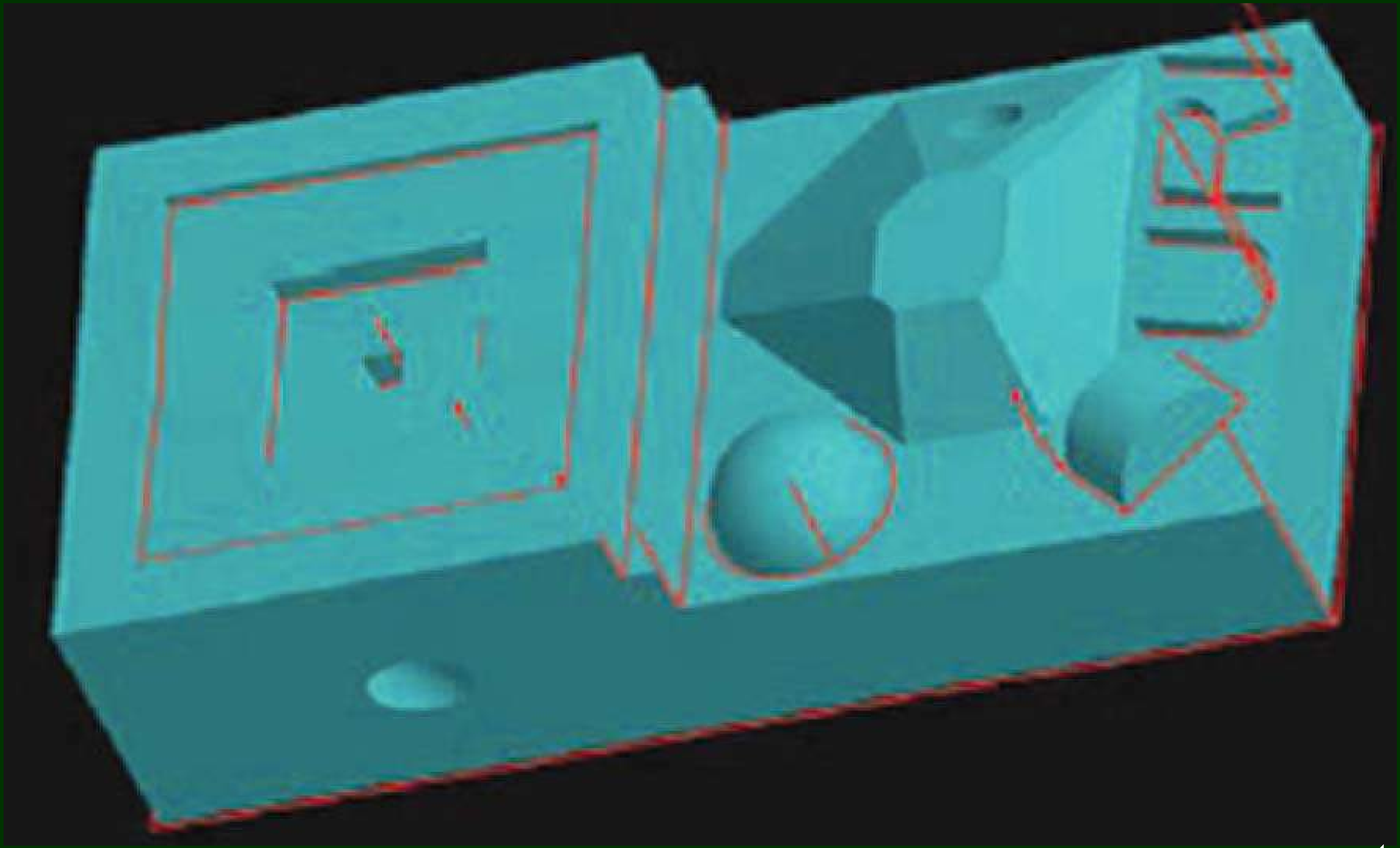
$$W_{\text{error}} = 2d - \delta_1 - \delta_2$$

- When δ1, δ2 become 0, W_{error}=2d. i.e the possible maximum error for a slot using raster milling is approximately two times the stepover distance

Sharp Edge Contour Machining…

- For complicated edges not parallel to the milling direction, raster milling is ineffective for creating smooth edges, as the edge will have a stair-step appearance, with the step size equal to the local stepover distance, d.
- After raster milling, it is advantageous to run a machining pass along the sharp edges (contours) of the part

Sharp Edge Contour Machining…



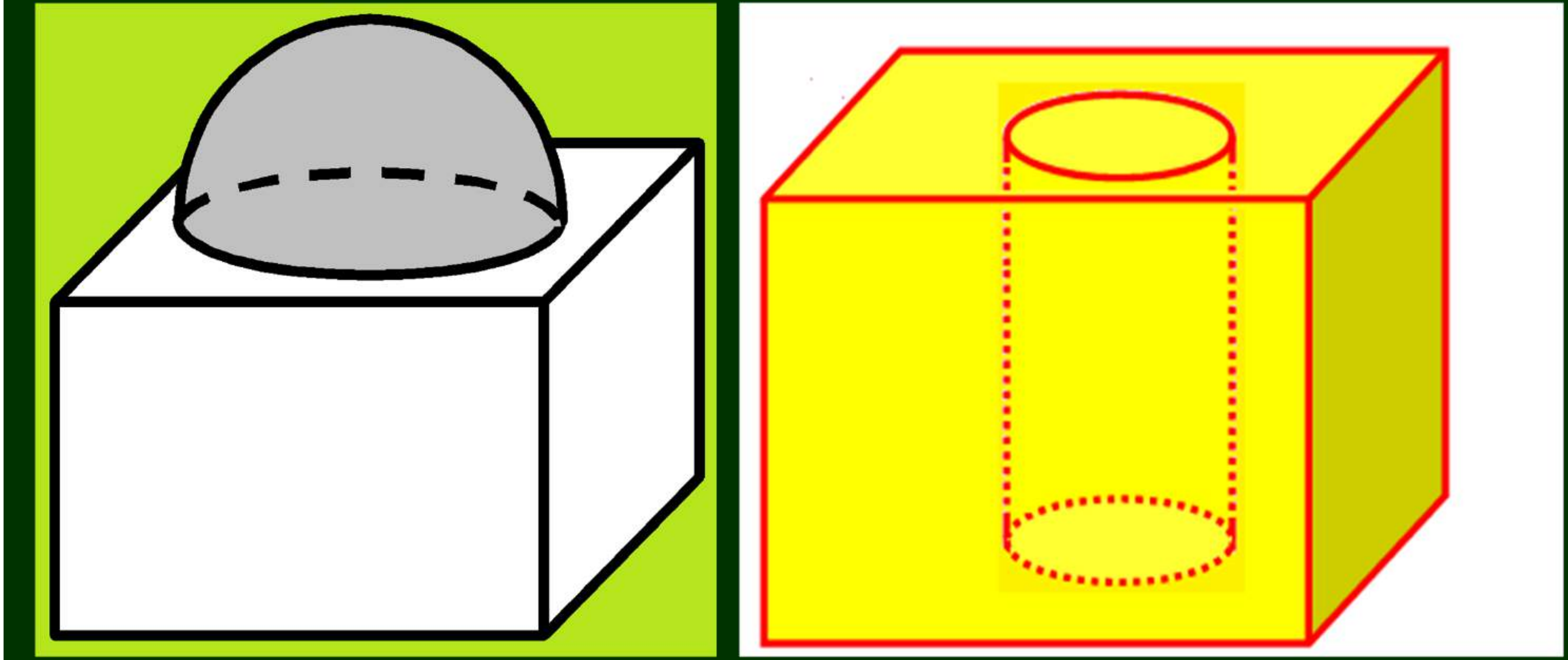
Hole Drilling

- Using milling tools to create holes is inefficient and the circularity of the holes is poor
- Challenging aspect is to recognize holes in an STL or AMF file, as the 3D geometry is represented by a collection of unordered triangular planar facets
- The intersection curve between a hole and a surface is typically a closed loop

Hole Drilling...

- A hole recognition algorithm begins by identifying all closed loops made up of sharp edges from the model
- Closed loops may not necessarily be the intersection curves between holes and a surface; hole-checking rules are used to remove the loops that do not correspond to drilled holes
- The remaining loops and their surface normal vectors are used to determine the diameter, axis orientation, and depth for drilling.
- Tool paths are then automatically generated

Hole Drilling…



Aesthetic Improvements

- AM parts may be displayed for aesthetic or artistic reasons or used as marketing tools.
- In these instances, the aesthetics of the part is of critical importance for its end application.
- Desired aesthetic improvement is solely related to surface finish
- If the color of the AM part is not of sufficient quality, then several methods can be used to improve the part aesthetics

Aesthetic Enhancement

- Effectively colored by simply dipping the part into a dye of the appropriate color
    - Suitable for parts created from powder beds, as the inherent porosity in these parts leads to effective absorption.
    - If painting is required, the part may need to be sealed prior to painting.
- Chrome plating (strengthens the part and improves wear resistance)
- Several materials can be electroless coated to AM parts, including Ni, Cu, and other coatings.
- In some cases, these coatings are thick enough that, in addition to aesthetic improvements, the parts are robust enough to use as tools for injection molding or as EDM electrodes

Aesthetic Improvements

Stereolithography part (**a**) before and (**b**) after chrome plating

Preparation for Use as a Pattern

- Patterns for:
  - investment casting
  - Sand casting
  - room temperature vulcanization (RTV) molding
  - spray metal deposition
  - other pattern replication processes
- Using AM pattern in a casting process is the least expensive way to produce a metal part, as many of the metal-based AM processes are still expensive to own and operate

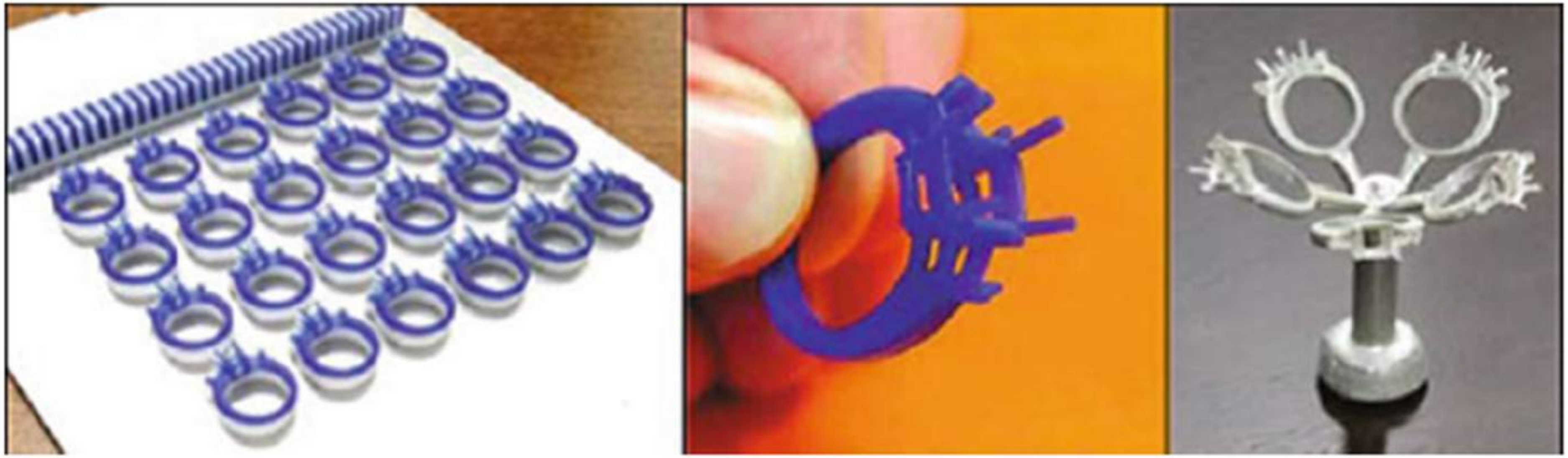
Preparation for Use as a Pattern…

- The accuracy and surface finish of an AM pattern will directly influence the final part accuracy and surface finish
- pattern must be scaled to compensate for any shrinkage that takes place in the pattern replication steps

Investment Casting Patterns

- In investment casting, the AM pattern will be consumed during processing. The residue left in the mold as the pattern is melted or burned out is undesirable.
- Any sealants used to smooth the surface during pattern preparation should be carefully chosen so as not to inadvertently create unwanted residue.
- AM parts can be printed on a casting tree or manually added to a casting tree after AM

Investment Casting Patterns



collection of rings on the build platform

close-up of the ring pattern

metal rings still attached to a casting tree

Rings for investment casting, made using a ProJet® CPX 3D Printer (Courtesy 3D Systems)

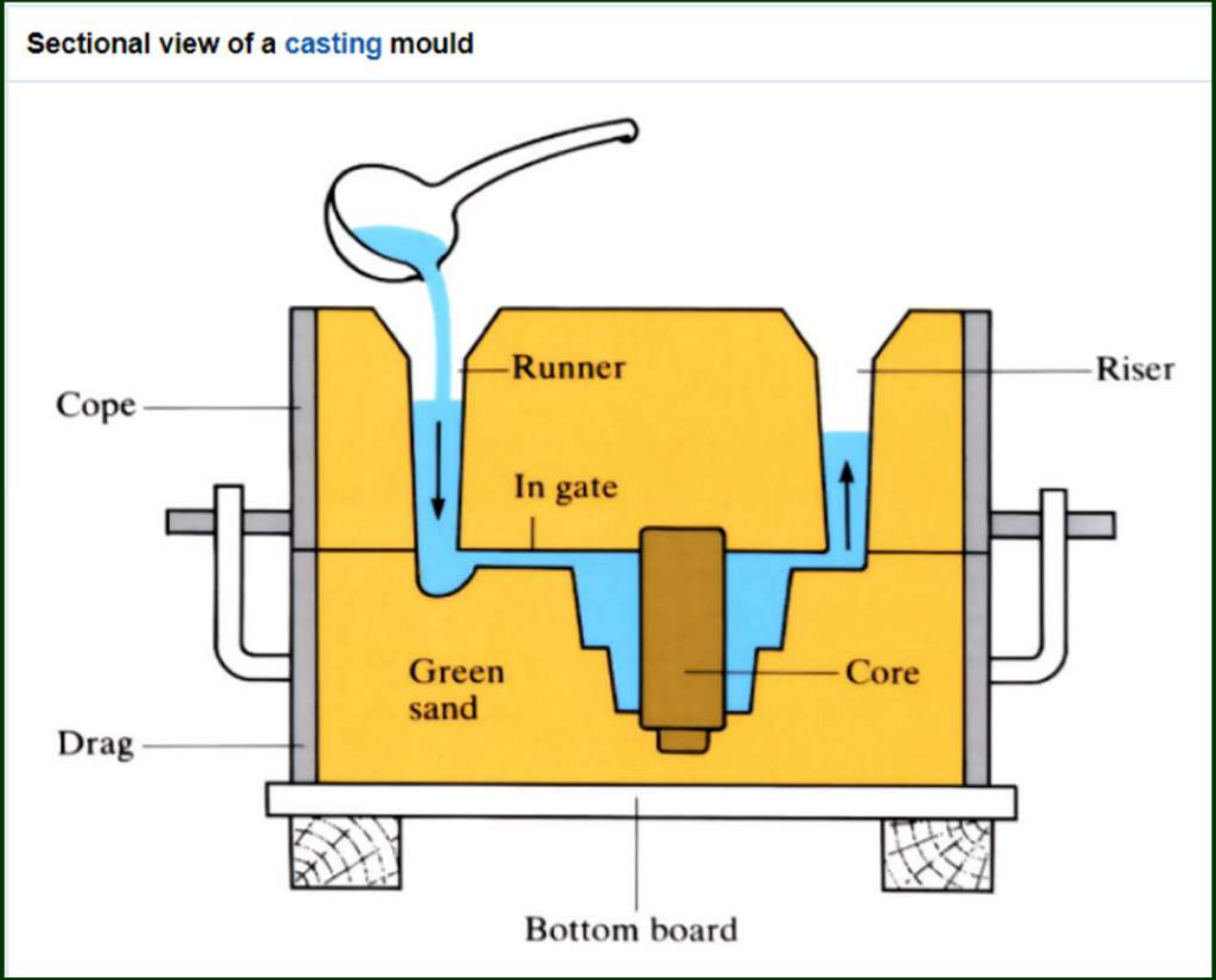
Investment Casting Patterns

- In SLA, the hollow, truss-filled shell patterns must be drained of liquid prior to investment. The hole(s) used for draining must be covered to avoid investment entering the interior of the pattern.
- Since photopolymer materials are thermosets, they must be burned out of the investment rather than melted.
- When powdered materials (SLS) are used as pattern, the resulting part is porous and brittle. To seal the part & strengthen it, the part is infiltrated with an investment casting wax.

Sand Casting Patterns

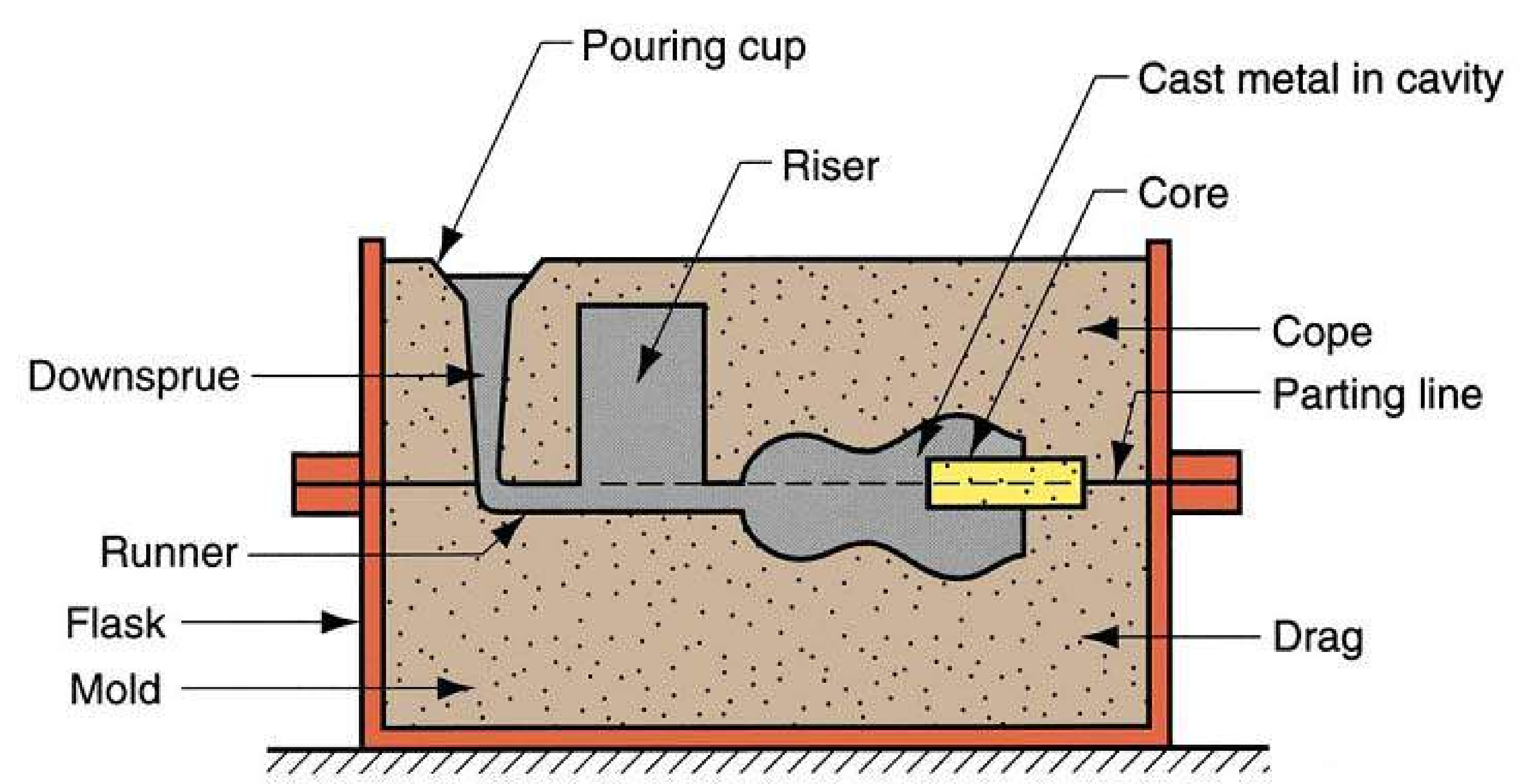
- Both binder jetting and PBF processes can be used to directly create sand mold cores and cavities by using a thermosetting binder to bind sand in the desired shape.
- Benefit - complex-geometry cores can be made that would be very difficult to fabricate using any other process
- AM sand casting patterns for casting: loose powder is removed, and the pattern is heated to complete cross-linking of the thermoset binder and to remove moisture and gaseous by-products.

Sand Casting Patterns

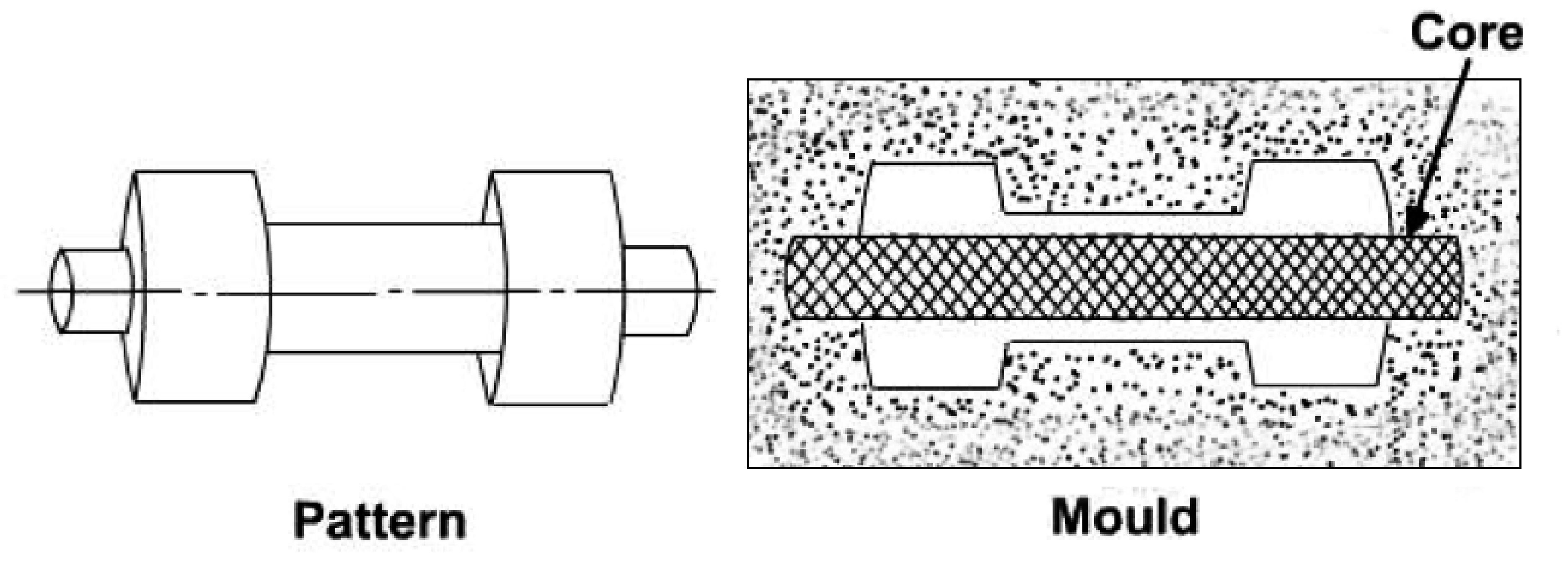


Sectional view of a casting mould

Sand Casting Patterns



Sand Casting Patterns



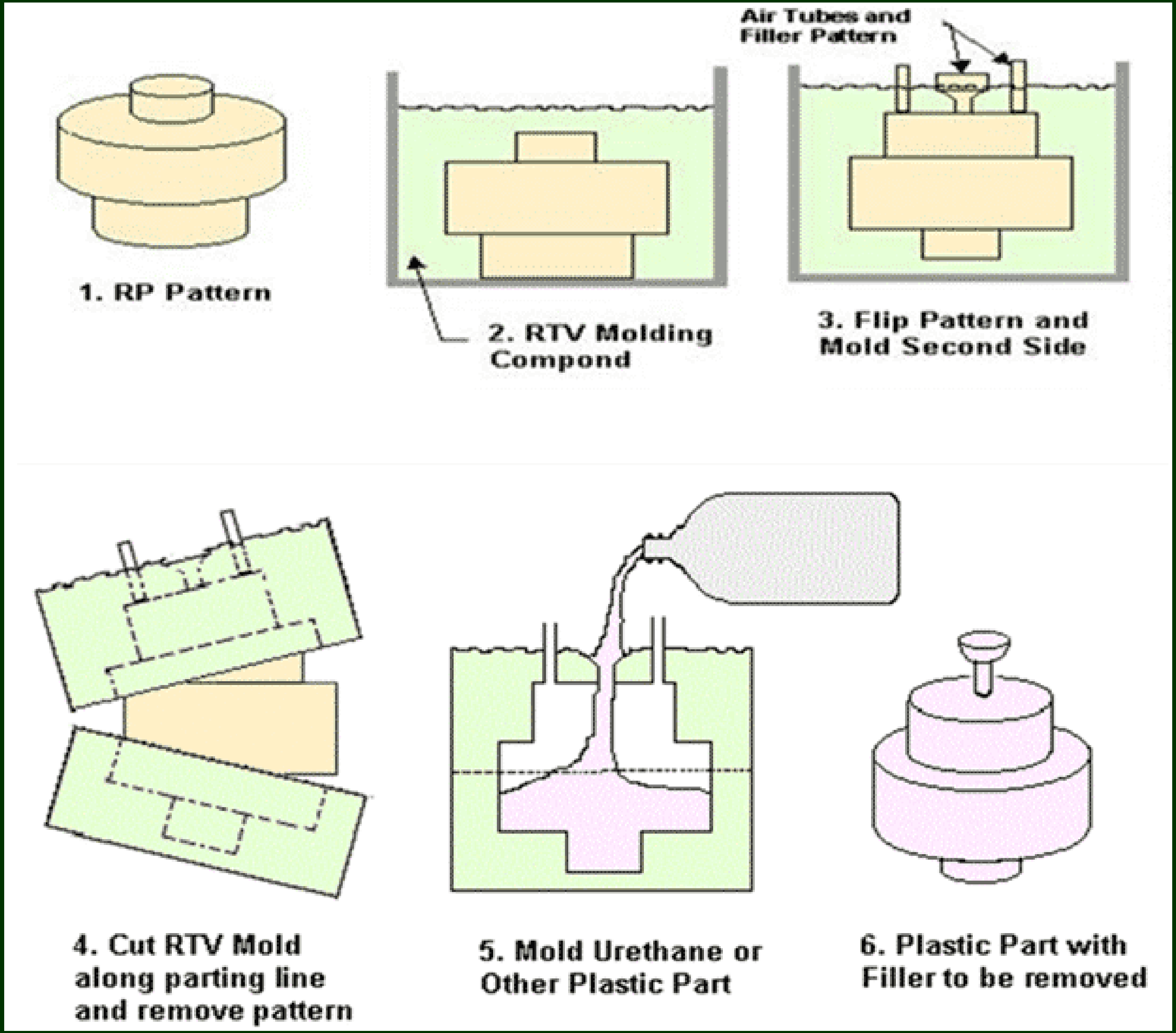
Sand Casting Patterns

- AM can also be used to create parts which are used in place of the typical wooden or metal patterns around which a sand-casting mold is created.
- AM pattern is placed in a box,
- sand is mixed with binder is poured around the part
- sand is compressed (pounded) so that the binder holds the sand together.

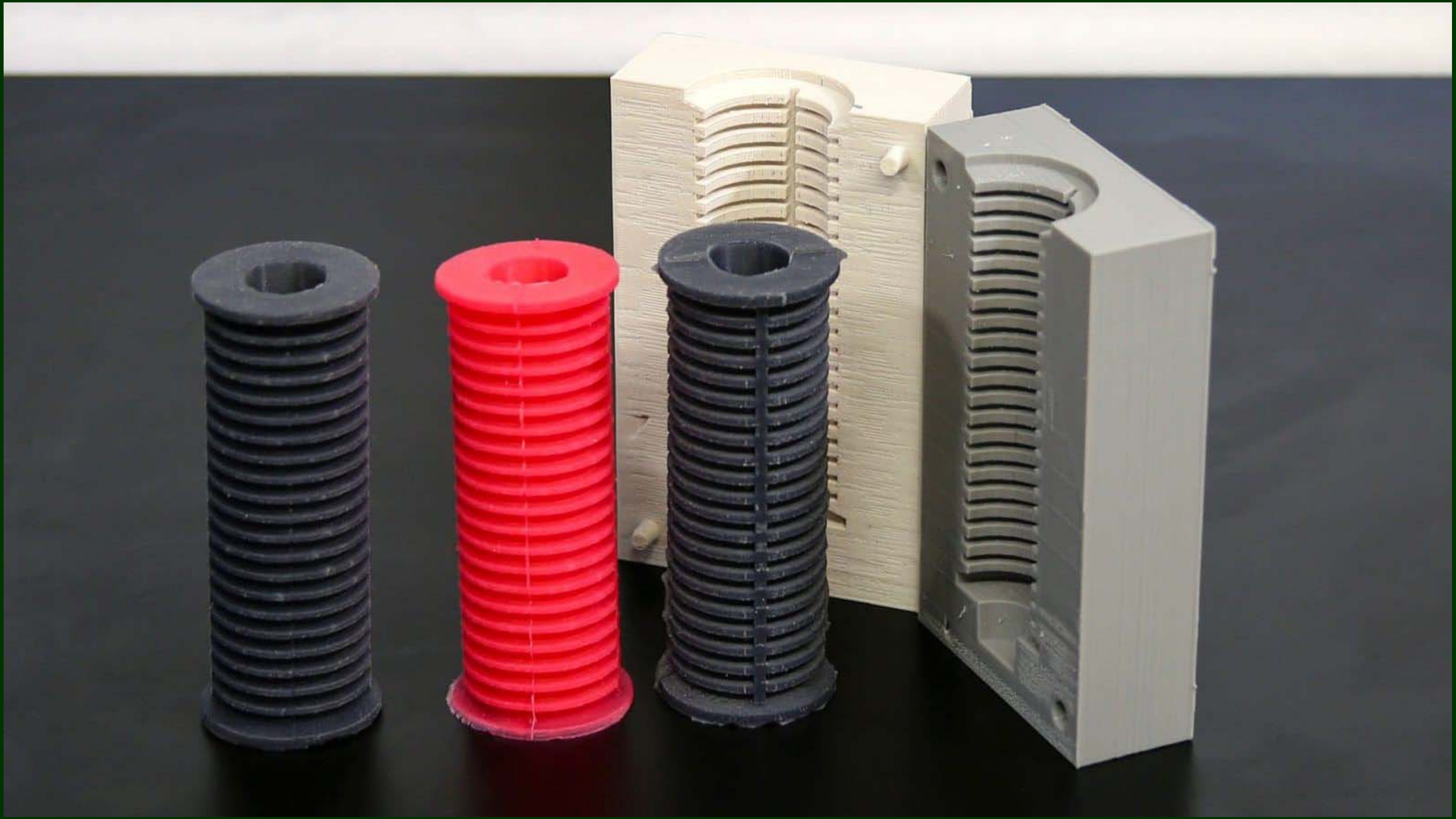
Other Pattern Replication Methods

- RTV (Room Temperature Vulcanization)molding or Silicone Rubber Molding
  - AM pattern is made (usually in SLA)
  - runners, risers, and gates are added
  - model is suspended in a mold box
  - rubber-like material is poured around the model
  - The rubber mold is removed from the mold box
  - knife is used to cut the rubber mold into pieces according to the parting line markers
  - the pattern is removed from the mold
  - used to make 10s or 100s of identical parts

RTV Process


Air Tubes and
Filler Pattern
1. RP Pattern
2. RTV Molding
Compond
3. Flip Pattern and
Mold Second Side
4. Cut RTV Mold
along parting line
and remove pattern
5. Mold Urethane or
Other Plastic Part
6. Plastic Part with
Filler to be removed

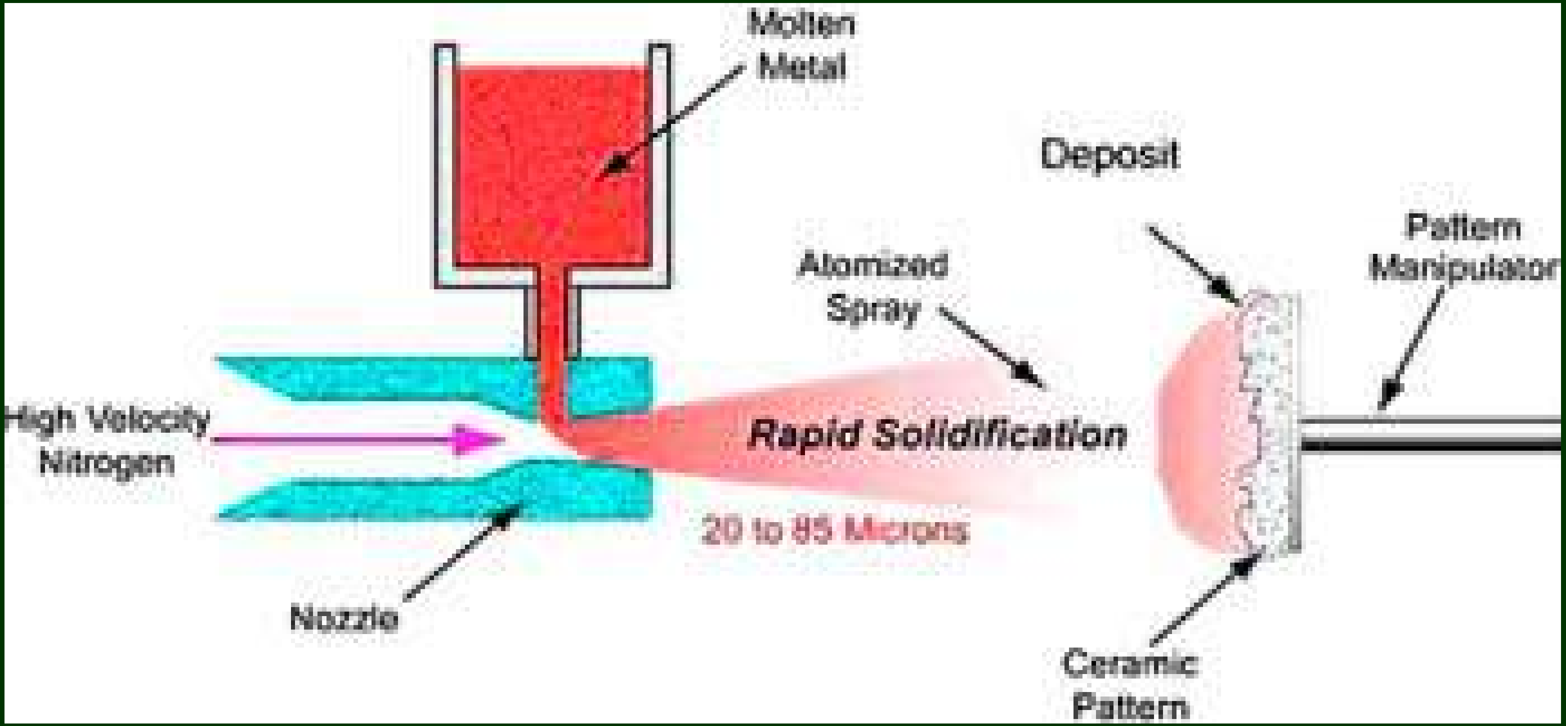
Silicone Rubber Molding



Metal Spray Processes

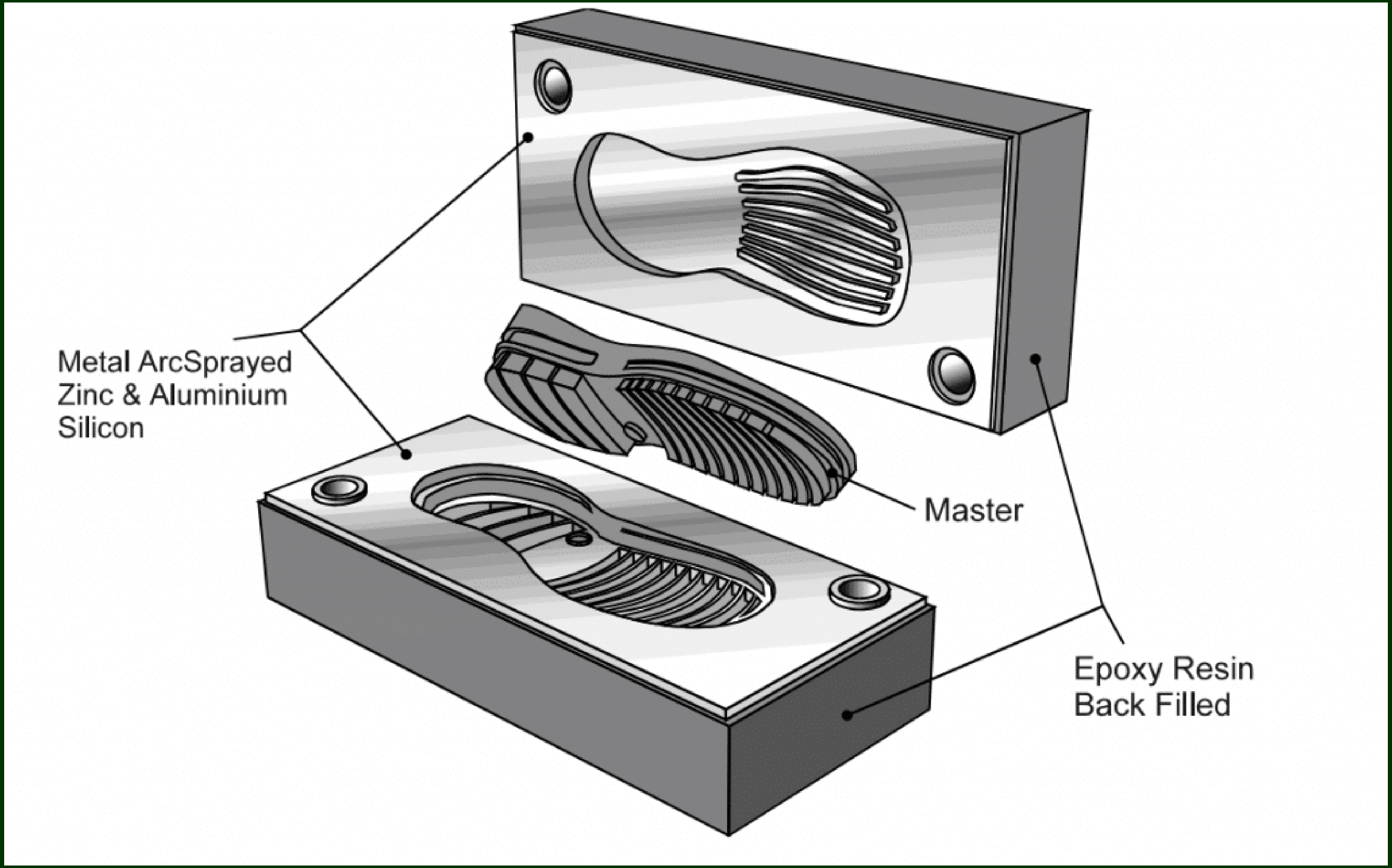
- To replicate geometry from an AM part into a metal part.
- Only one side of the pattern is replicated into the metal part
- Using spray metal or electroless deposition processes, an AM pattern can be replicated to form an injection molding cavity, which can then be used to mold other parts

Metal Spray Processes



Metal Spray Processes

Metal Spray Processes



Property Enhancements Non-thermal Techniques

- Powder-based and extrusion-based processes often create porous structures
- Porosity can be infiltrated by a higher-strength material, such as cyanoacrylate (strong fast-acting adhesive)
- Proprietary methods and materials have been developed to increase the strength, ductility, heat deflection, flammability resistance, EMI shielding, and other properties using infiltrates and nano-composite reinforcements.

Property Enhancements Non-thermal Techniques

- SLA - many photopolymers do not achieve complete polymerization
- Post-Cure Apparatus: a device that floods the part with UV and visible radiation in order to completely cure the surface

Property Enhancements - Thermal Techniques

- Thermally processed to enhance their properties
- In DED (Directed Energy Deposition) & PBF (Powder Bed Fusion)[SLS/EBM] it is primarily heat treatment to form the desired microstructures and/or to relieve residual stresses
- In some cases, special heat treatment methods are adopted to retain the fine-grained microstructure while still providing stress relief and ductility enhancement.

Property Enhancements - Thermal Techniques

- Before DED & PBF(directly process metals and ceramics) many techniques were developed for creating metal and ceramic green parts using AM.
- These were then furnace post-processed to achieve dense, usable metal and ceramic parts.

Green Parts

- **Green Part**: a polymer coated metallic powder, or a mixture of metallic and polymer powders are used for part construction. The polymer binder is melted and binds the particles together, and the metal powder remains solid. The metallic powder particles remain largely unaffected by the heat of the laser.
- The polymer-bound green parts are subsequently furnace processed in two stages: (1) debinding and (2) infiltration or consolidation.
- During debinding, the polymer binder is vaporized to remove it from the green part. Typically, the temperature is also raised to the extent that a small degree of necking (sintering) occurs between the metal particles.
- Subsequently, the remaining porosity is either filled by infiltration of a lower melting point metal to produce a fully dense metallic part, or by further sintering and densification to reduce the part porosity.

End of Unit - 4

ME 18002
3D Printing & Design

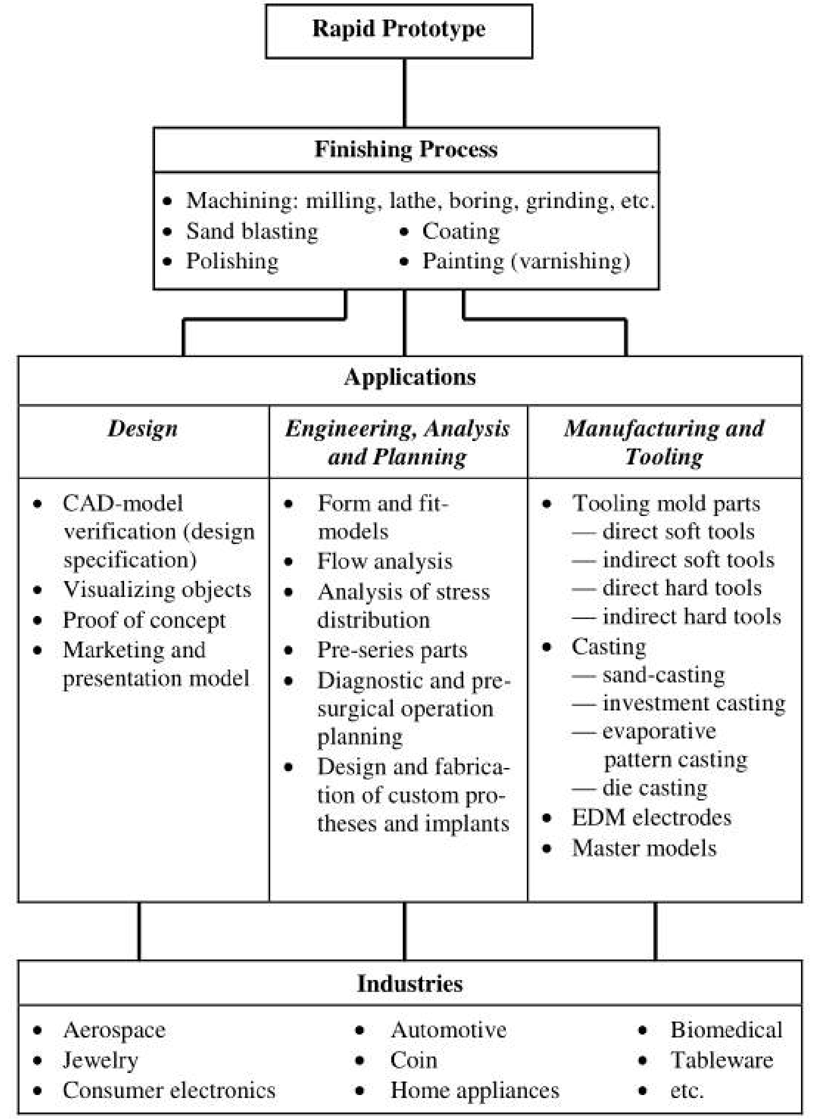
Unit - 5

APPLICATIONS OF AM

Unit 5 - Contents

- Functional models
- Pattern for investment and vacuum casting
- Medical models
- Art models
- Engineering Analysis Models
- Rapid Tooling
- New materials development
- Bi-metallic parts
- Re- manufacturing
- Application examples for
    - Aerospace
    - Defence
    - Automobile
    - Bio-medical
    - General engineering industries

Application Areas of AM



Rapid Prototype

Finishing Process

- Machining: milling, lathe, boring, grinding, etc.
- Sand blasting
- Polishing
- Coating
- Painting (varnishing)

Applications

Design	*Engineering, Analysis and Planning*	*Manufacturing and Tooling*
• CAD-model verification (design specification) • Visualizing objects • Proof of concept • Marketing and presentation model	• Form and fit-models • Flow analysis • Analysis of stress distribution • Pre-series parts • Diagnostic and pre-surgical operation planning • Design and fabrication of custom protheses and implants	• Tooling mold parts — direct soft tools — indirect soft tools — direct hard tools — indirect hard tools • Casting — sand-casting — investment casting — evaporative pattern casting — die casting • EDM electrodes • Master models

Industries

- Aerospace
- Jewelry
- Consumer electronics
- Automotive
- Coin
- Home appliances
- Biomedical
- Tableware
- etc.

Application Areas of AM

Functional modelers

- Functional modelers are higher-end Additive Manufacturing systems that build parts larger, more accurate, and more durable than the office modeler systems

- Functional modelers are usually larger and more expensive, and often are more suitable for shop-floor or laboratory operation as opposed to a design or office environment.

Functional Models

- Many AM technologies now meet the need for building functional prototypes with material properties close to those of production parts.
- Widely used AM process for producing models for functional tests are:
  - SLA
  - FDM
  - SLS
  - LENS
  - 3DP

Patterns for Investment and Vacuum Casting

- AM technologies are widely used for building patterns for investment and vacuum casting.
- Models built using
  - SLA
  - SLS
  - FDM

  can be used as patterns for both casting processes.

Medical Models

- Operation planning. Using real size AM models of patients' pathologic regions, surgeons can much more easily understand physical problems and gain a better insight into the operations to be performed.
- AM models can also assist surgeons in communicating the proposed surgical procedures to the patients.

- Surgery rehearsal. AM models allow surgeons & surgical teams to rehearse complex operations using the same techniques and tools as during actual surgery. Potentially, such rehearsals can lead to changes in surgical procedures and significantly reduce risk.

Medical Models…

- Training. AM models of specimens of unusual medical deformities can be built to facilitate the training of student surgeons and radiologists.
- The models can also be used for student examinations.

- Prosthesis design. AM models can be used to fabricate master patterns which are then replicated using a bio-compatible plastic material. Implants produced in this way are much more accurate and cost effective than those produced employing conventional techniques.

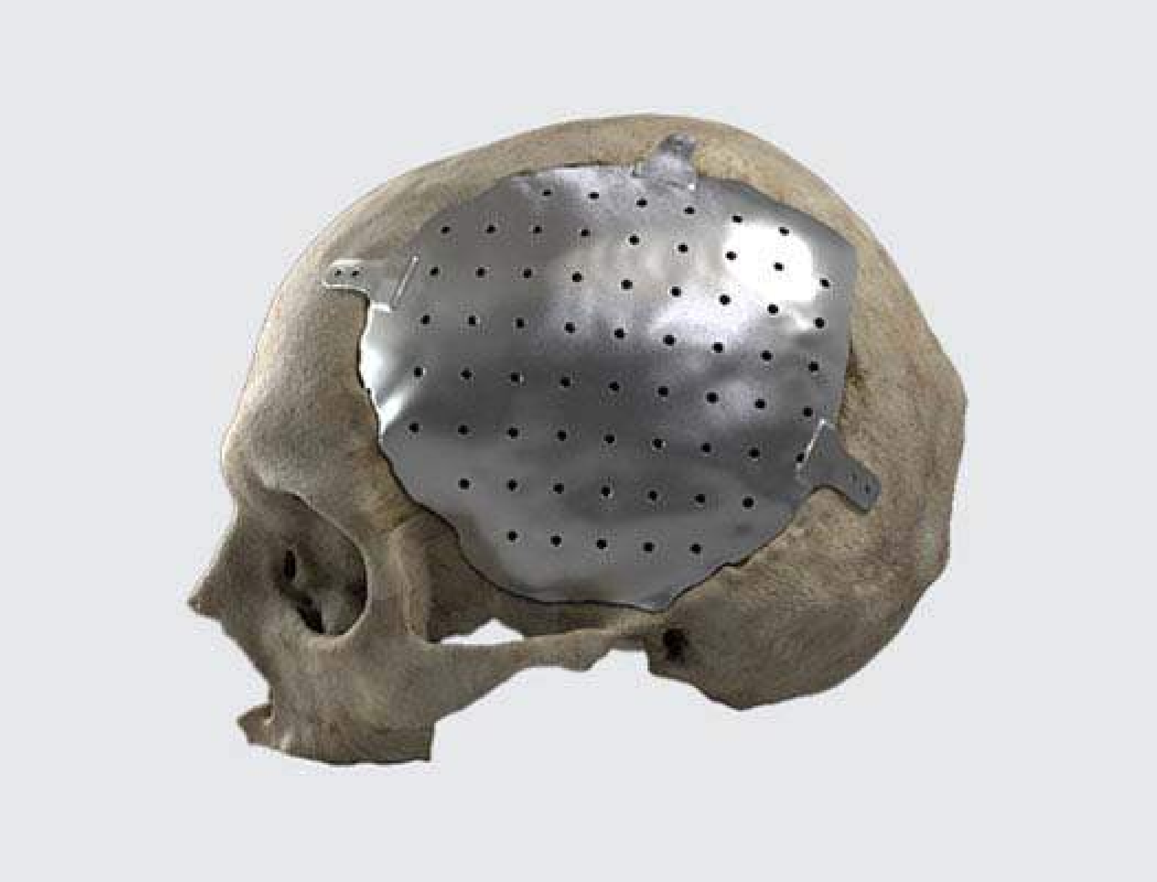
Building Medical Models

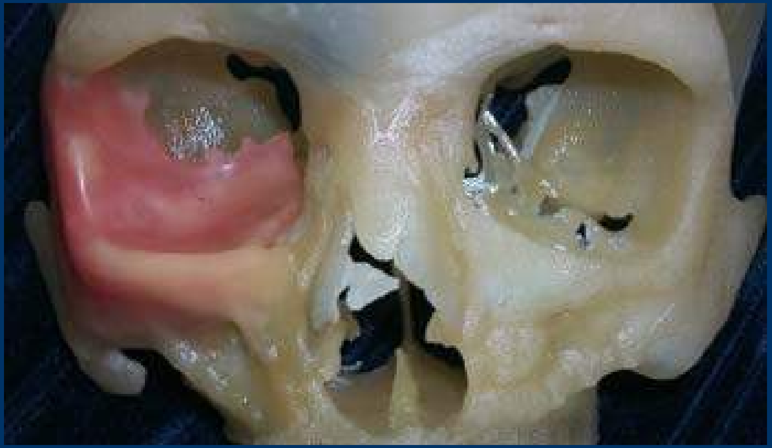
- Data acquisition with medical equipment: CT Scans, MRI Scans, 3D Ultrasound

- Generation of STL files from the scan data. Interactive software tools exist for segmentation of scanned images and generation of STL files. MIMICS software

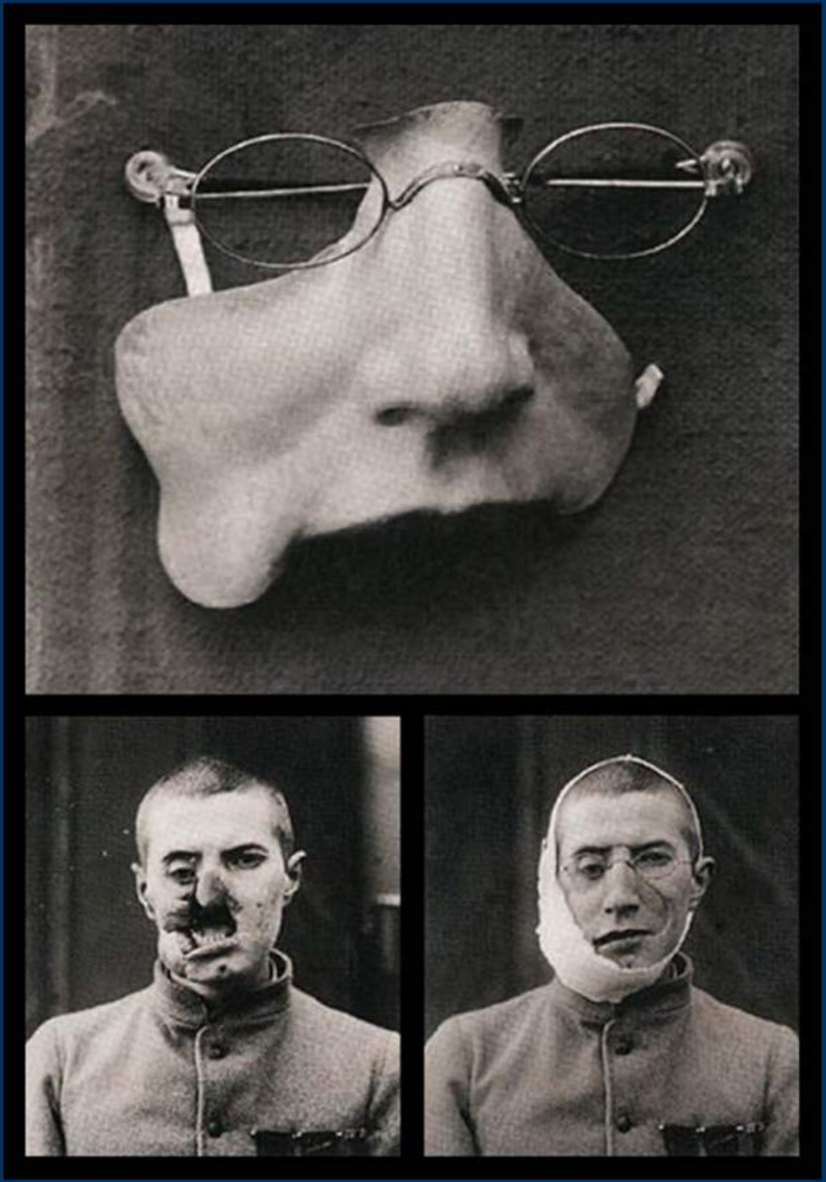
- Building AM models from the generated STL files. Any AM technology can be employed for building medical models.

Customised Implants





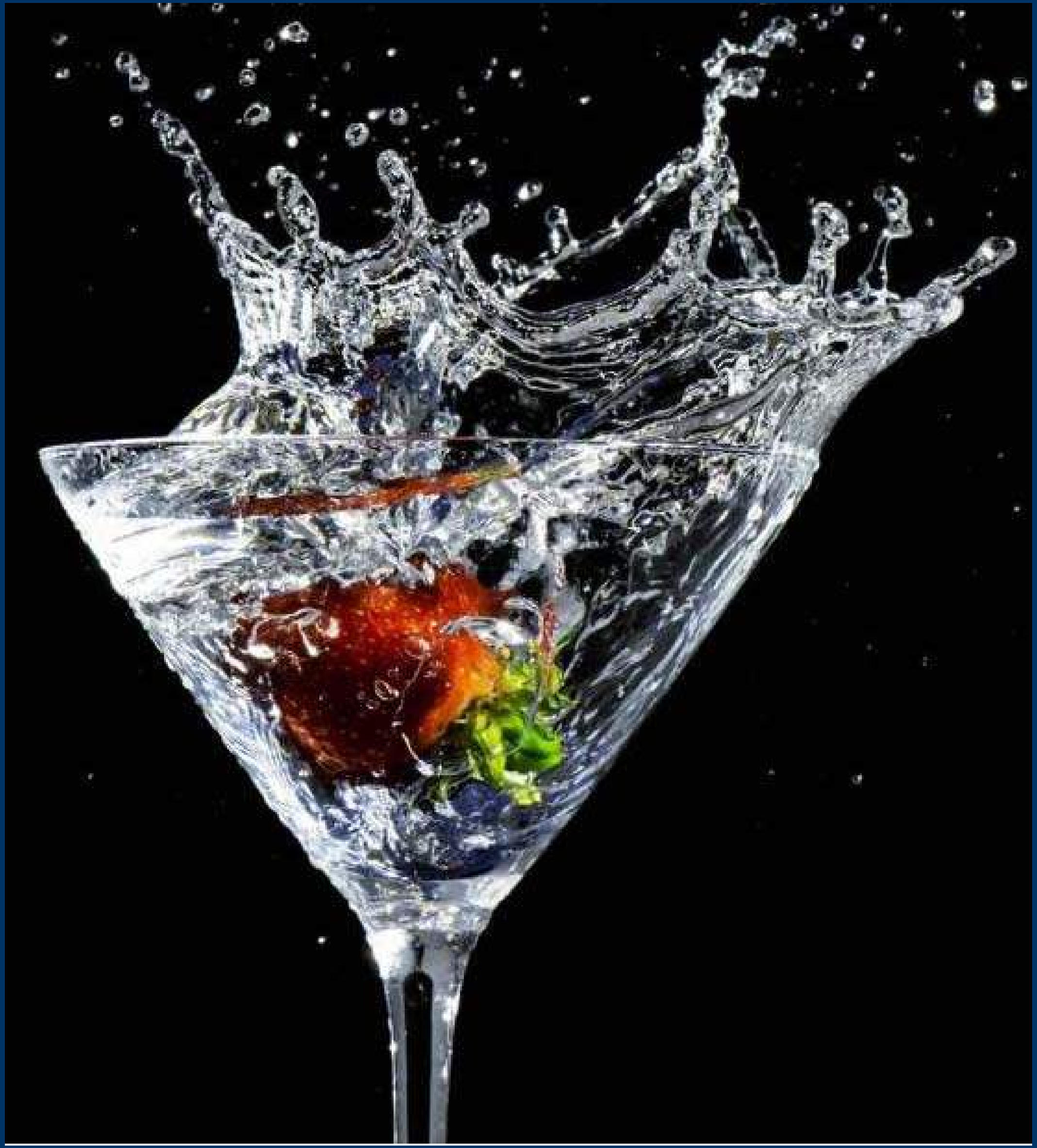
Customised Implants



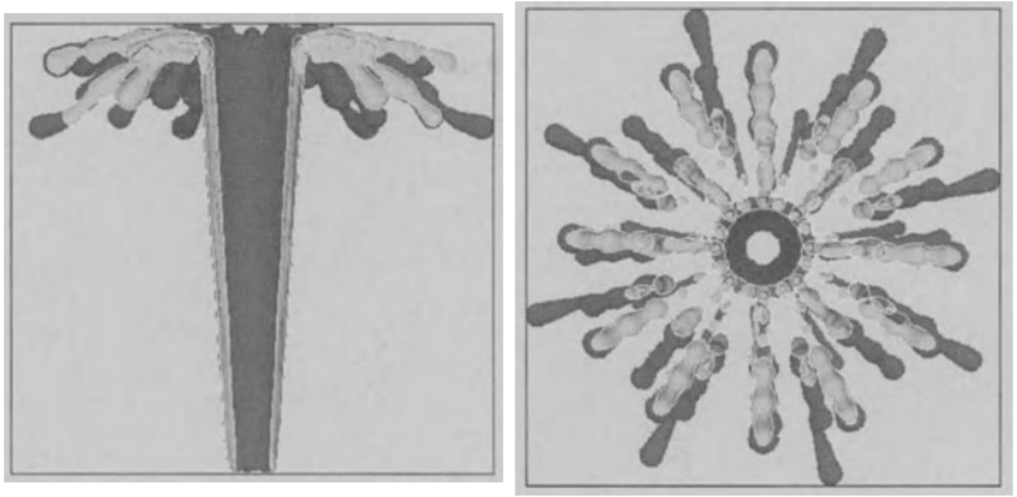
Art Models

- Artists can experiment with complex artworks which support and enhance their creativity
- Initially, the high cost of AM models set strict limits on the size of the models
- Introduction of Concept Modellers, has made it cost effective
- Considering the accuracy and the AM materials available, Concept Modellers are more than adequate for most art applications.

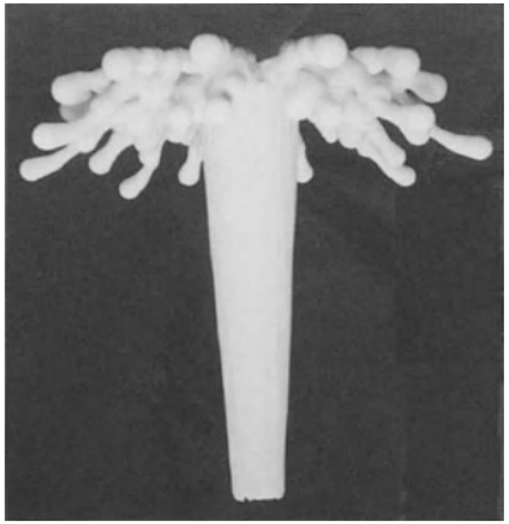
Art Model – Case Study



Art Model – Case Study



Cross-sections of the 3D model of a water splash



SLS model representing a water splash

Engineering Analysis Models

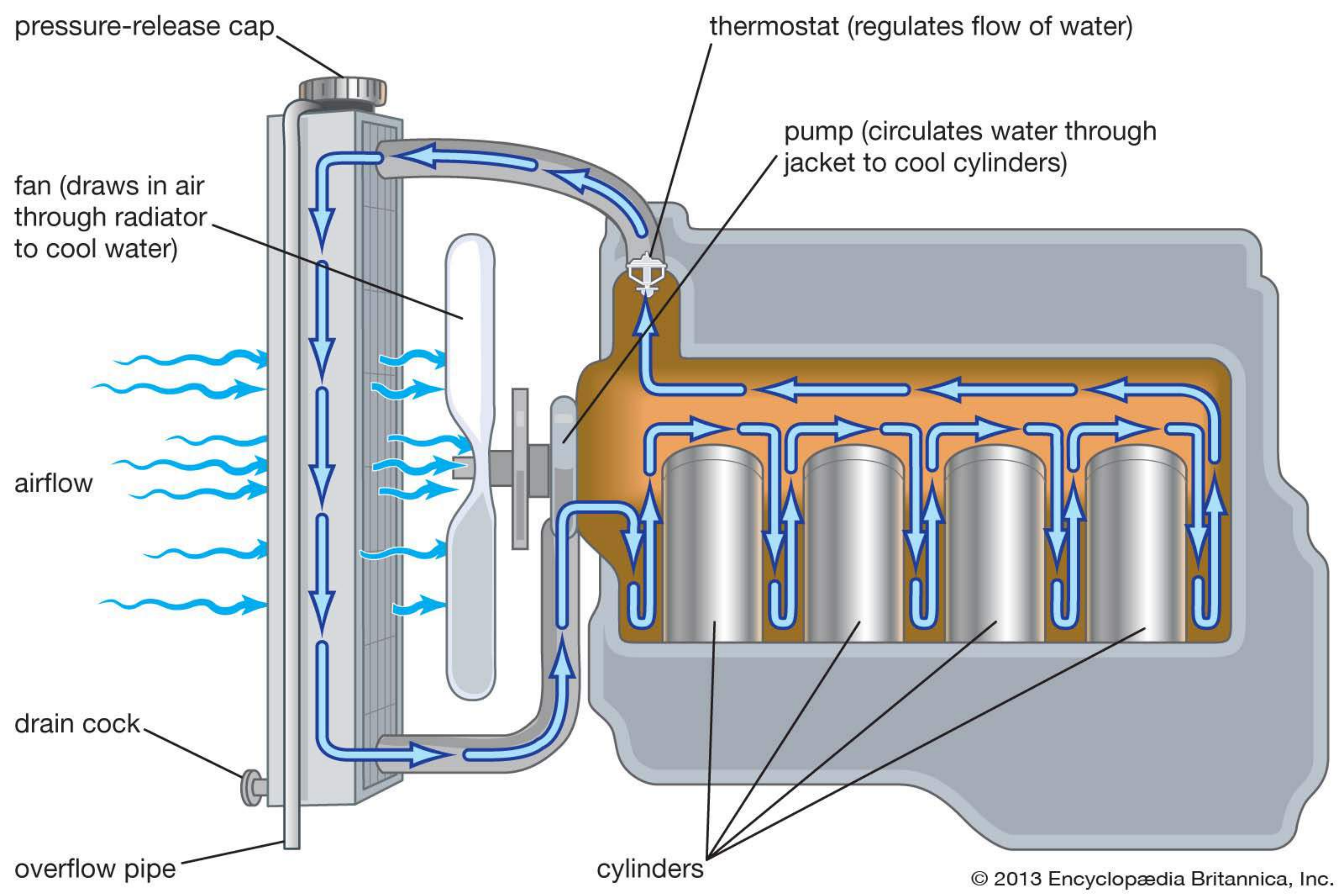
- Computer Aided Engineering (CAE) analysis is an integral part of Time- Compression technologies
- Software based on FEA are used to speed up the development of new products by initiating design optimization before physical prototypes are available
- Creation of accurate FEA models for complex engineering objects sometimes requires significant amounts of time and effort
- AM techniques makes it possible to begin test programmes on physical models much earlier and complement the CAE data.

Applications of AM models
in
Engineering Analysis

Visualisation of Flow Patterns

- SLA models were used to optimise the cross-flow jacket of a V6 high-performance racing engine
- 60 sensors were installed to monitor local flow temperature and pressure conditions.
- The coolant flow patterns were visualised by accurately injecting very small air bubbles.
- The flow patterns were recorded by high-speed video. The analysis provided valuable data about stagnation zones and insufficiently cooled sections.
- The critical sections were redesigned & SLA models of the modified components were produced.
- Each design iteration took one week.

Engine Cooling System



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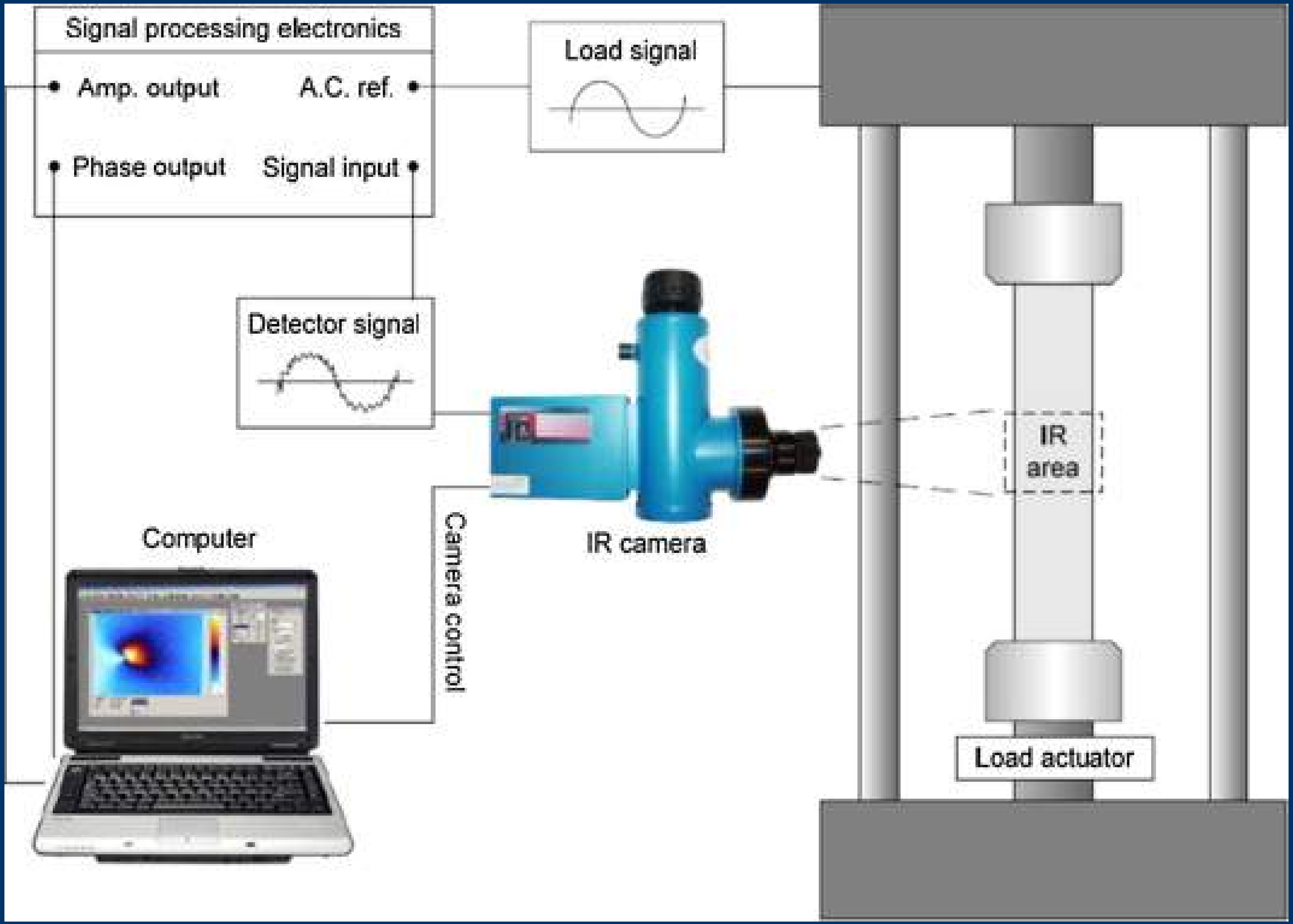
Thermo Elastic Tension Analysis

Also called Thermoelastic Stress Analysis

- Stress changes in an elastic solid are accompanied by small temperature changes which are directly related to the stress change.
- The surface temperature changes are measured using a sensitive infrared detector.
- This technique is very useful to validate structural finite element modelling (FEM) and to predict stress concentration in real components.

Thermoelastic Stress Analysis



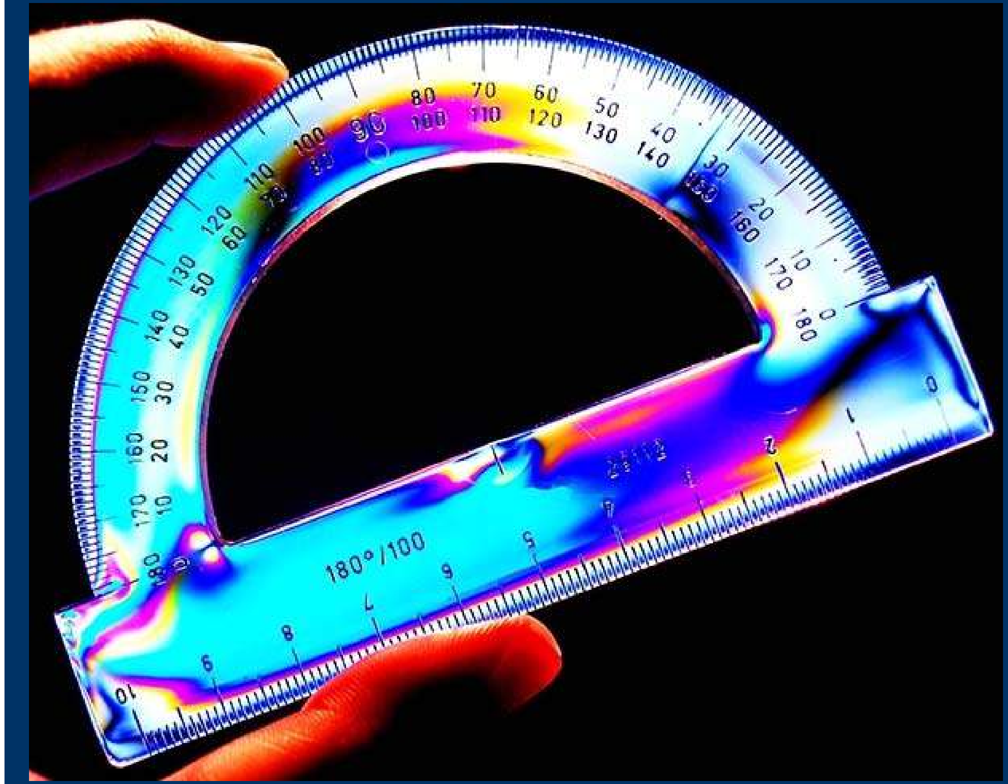
THESA – Case Study

- SLS models built in glass-filled nylon were utilised to optimise the design of a highly loaded wheel rim of a sports car
- Initially, a rim segment was produced in several AM materials to find the optimal material for the THESA investigation.
- The temperature patterns of the glass-filled nylon model were very similar to those obtained from cast metal parts.

Photoelastic Stress Analysis

- Photoelasticity describes changes in the optical properties of a materials, glass and polymer, under mechanical deformation. It is a property of all dielectric media and is often used to experimentally determine the stress distribution in a material
- Polarized light is passed through transparent, loaded models and stress fields are interpreted from the formation of interference fringes.
- The art or process of making observations with the polariscope is called polariscopy.
- This analysis of SLA models can be transferred to functional metal parts by employing fundamental similarity laws

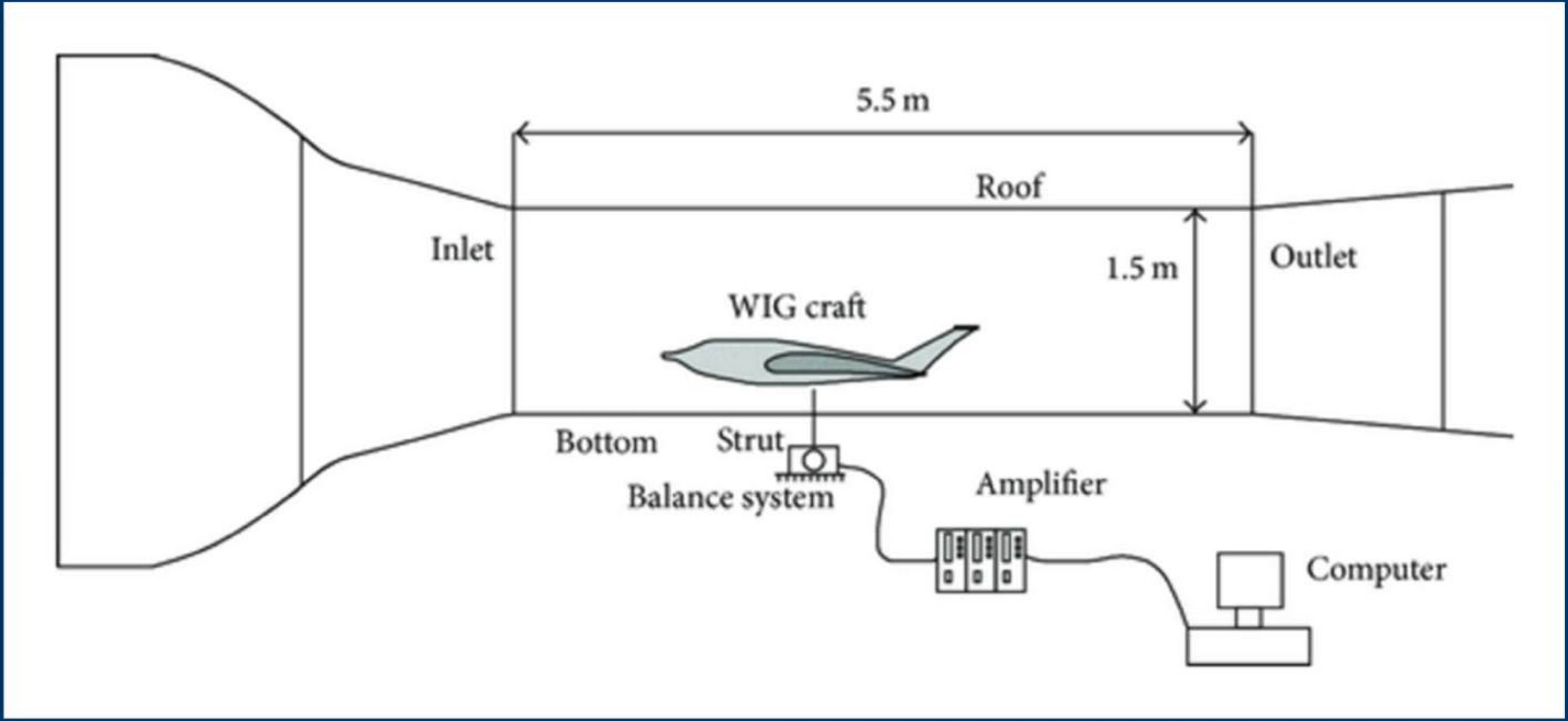
Photoelastic Stress Analysis



Models for Wind Tunnel Tests.

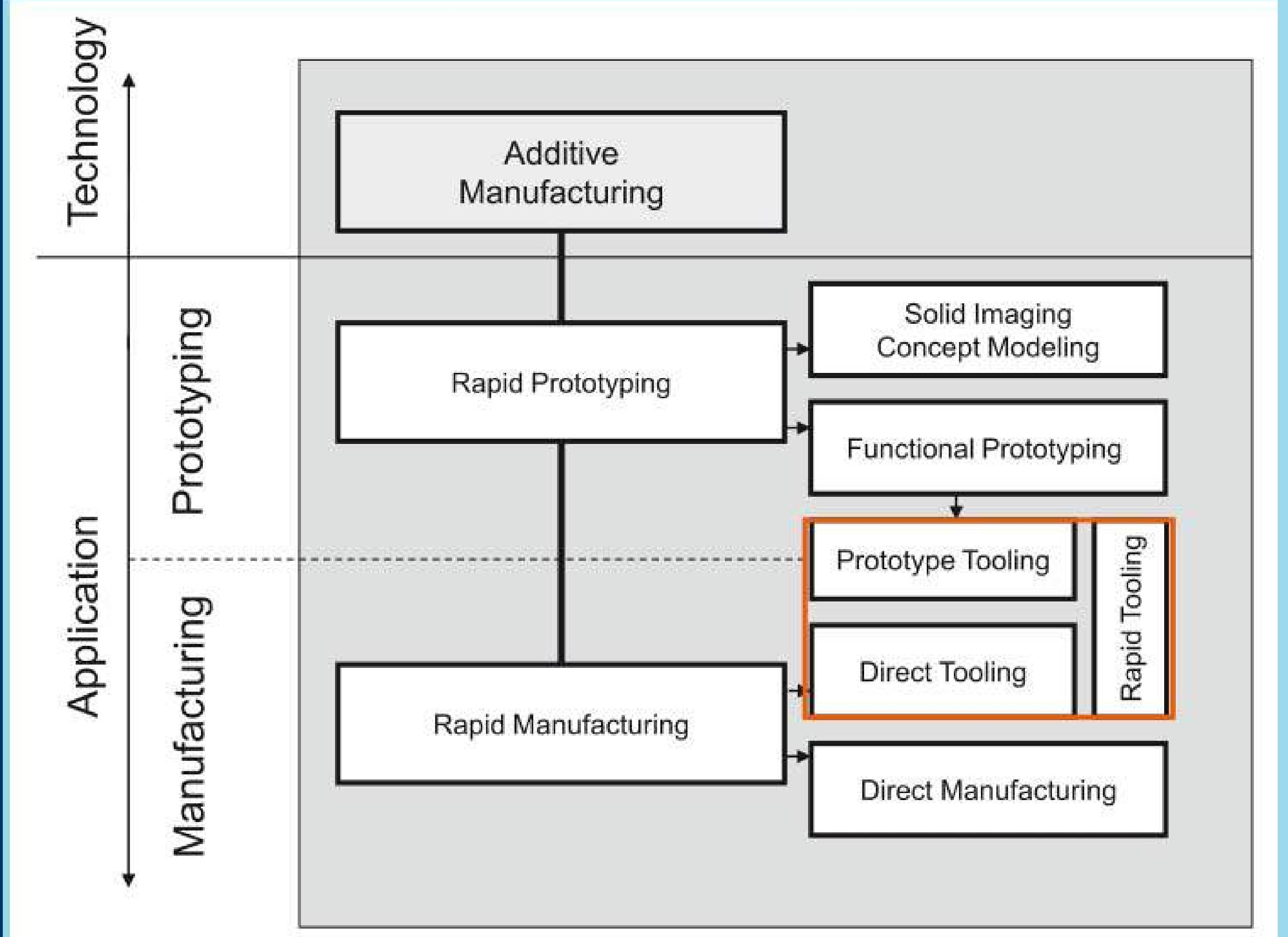
- Despite advances in CAE tools, the aerospace and automotive industries still rely on experimental wind tunnel test data to verify the performance of new designs
- AM techniques can be used to produce wind tunnel models which are not subjected to significant loads
- The strength, accuracy and surface finish of models produced using SLA, SLS, FDM and SGC technologies are sufficient for tests of non-structurally loaded parts
- SLS models produced in RapidSteel or metal models fabricated from RP patterns are adequate for lightly loaded applications.

Models for Wind Tunnel Tests



Models for Wind Tunnel Tests

Rapid Tooling



Rapid Tooling

Rapid Tooling

- Rapid tooling refers to mold cavities that are either directly or indirectly fabricated using additive manufacturing (AM) techniques.

- Soft tooling - 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.

Rapid Tooling

- Soft tooling produces short-run production patterns (1 to 1,000 parts).

- Injected wax patterns (master pattern) can be used to produce castings or injected plastic parts may be used directly in given applications.

- Soft tools cost ten times less than a machined tool

Direct Rapid Prototyped Tooling

- LENS , 3DP, SLS provide rapid prototyped metal tooling capable of fabricating several thousand parts before tool failure.
- They are durable enough to withstand the pressures and temperatures associated with low-volume injection molding
- In SLS & 3DP, the components must be post-sintered and infiltrated with a lower temperature metal prior to being rigid enough to use.

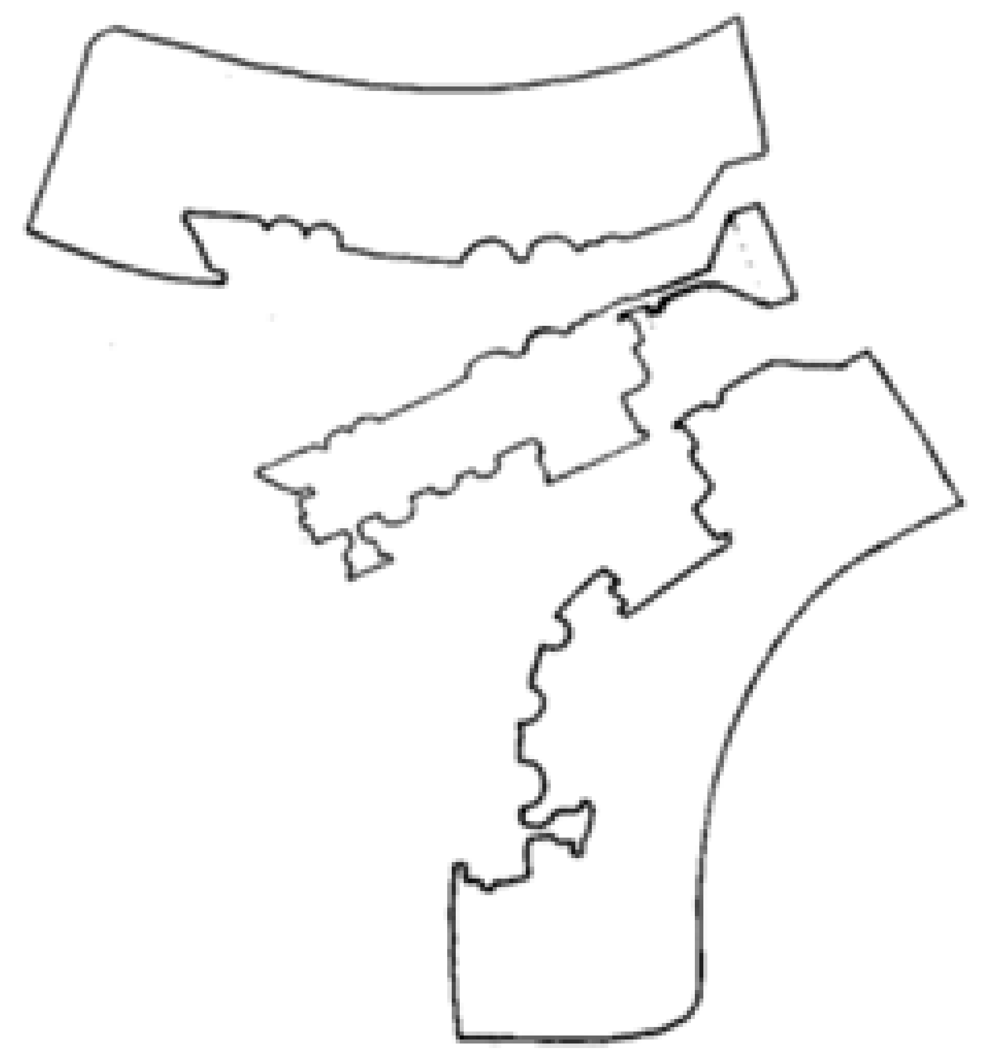
Direct Rapid Prototyped Tooling

- LENS parts are directly usable strength-wise but doesn't provide adequate surface finish for most injection-molding requirements.
- SLA can also be used to fabricate short-run tooling as well.
- SLA tools have run up to 100 parts prior to failure but are typically used for quantities less than 50.

Silicone Rubber Tooling

- It is a method of soft tooling
- Rapid prototyped model is used as a pattern for a silicone rubber mold, which can be used for short runs.
- RTV silicones are preferable as they do not require special curing equipment.
- This rubber-molding technique yields a flexible mold that can be peeled away from more intricate patterns as opposed to firmer mold materials.

Silicone Rubber Tooling-Flexible Mold



Investment-cast Tooling

- The process is the same as investment casting the actual component, except that the tool is cast instead.

- The AM process is used to produce a model of a negative which can be taken through a casting process to produce a metal mold, which in turn can survive many injections.

- This approach, unfortunately, allows for more dimensional error due to the many steps involved.

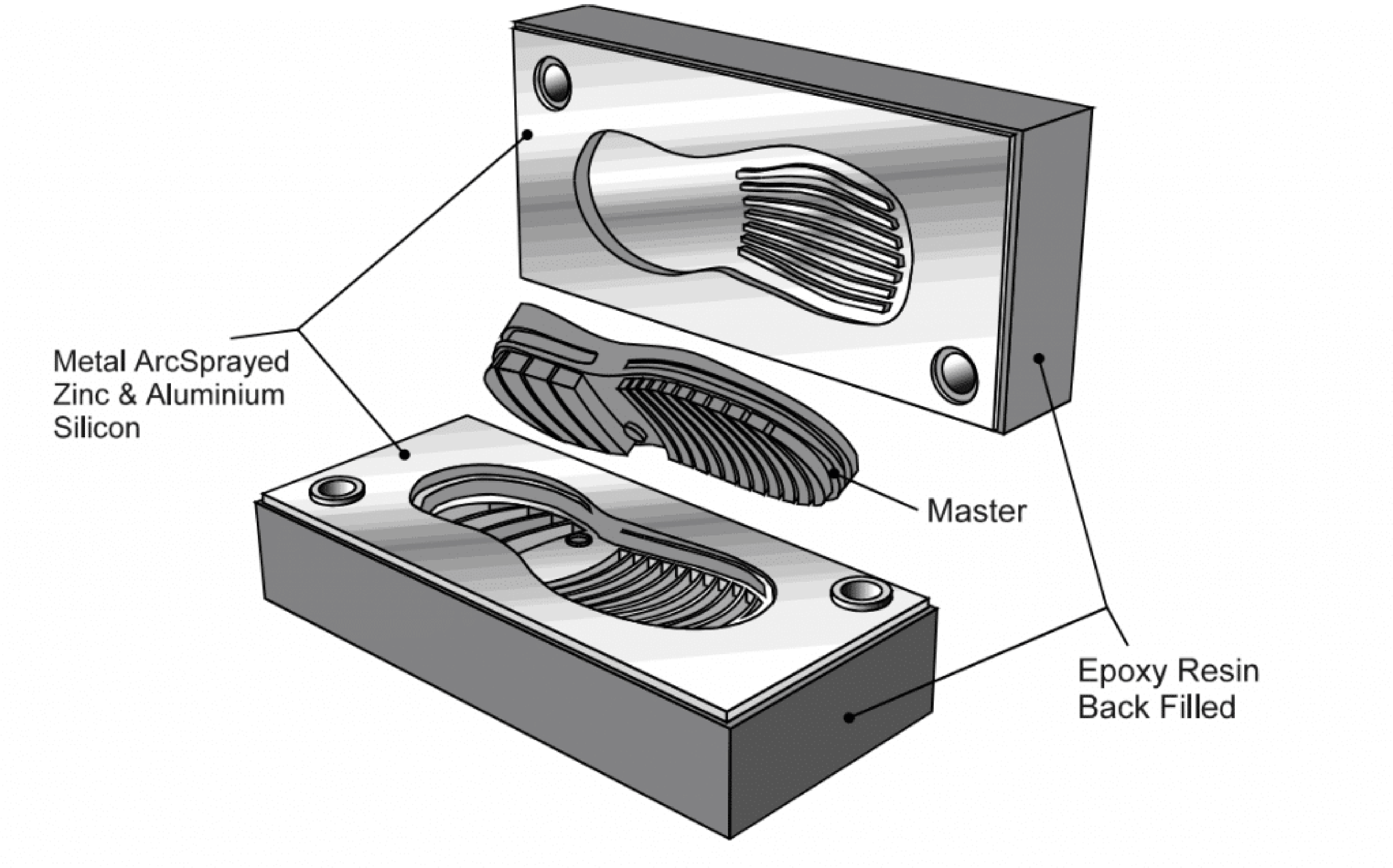
Powder Metallurgy Tooling

- Tools and inserts fabricated using powder metallurgy (P/M) provide long-life service comparable to machined tools, however they are made from rapid prototyped patterns.
- Process called SDKeltool, is owned 3D Systems, Corp.
- A rapid-prototyped negative master is used to create a silicone-rubber positive.
- A proprietary metal mixture is then injected or poured around the positive and is sintered to shape.
- Properties of P/M tools are similar to a tool steel, providing hundreds of thousands of parts prior to failure.

Spray Metal Tooling

- Thermal metal deposition technologies such as wire-arc spray and vacuum-plasma deposition are being developed to essentially coat low-temperature substrates with metallic materials.
- This results in a range of low-cost tools that can provide varying degrees of durability under injection pressures.
- The concept is to first deploy a high-temperature, high-hardness shell material to an AM positive, and then backfill the remainder of the tool shell with inexpensive low-strength, low-temperature materials and cooling channels (if necessary).

Spray Metal Tooling



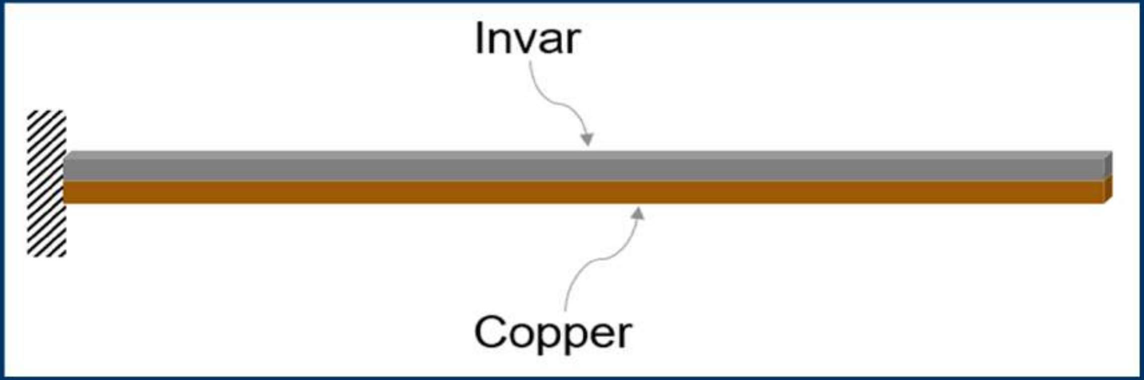
Desktop Machining

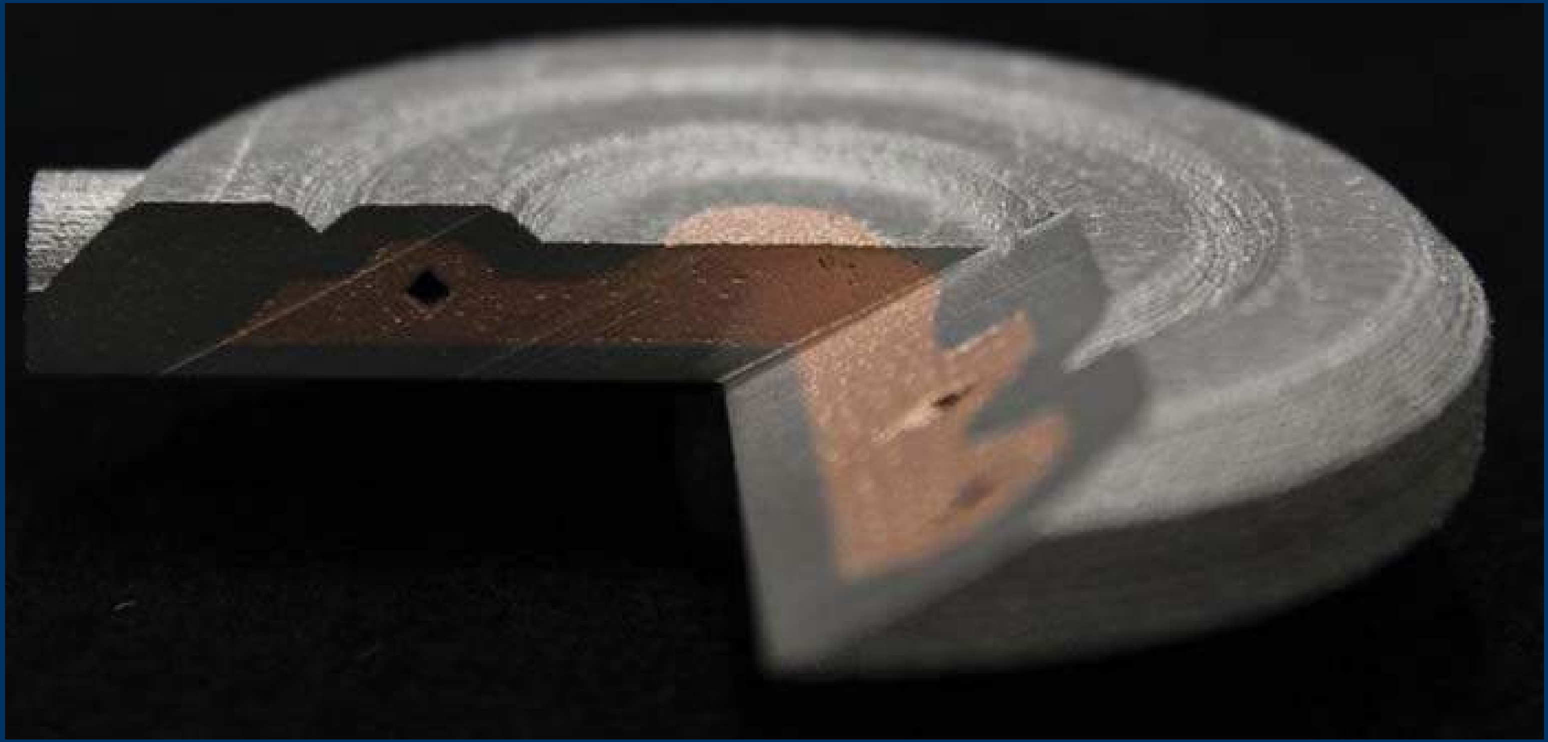
- Although RP is considered an alternative to machining, small, portable machining centers are now being produced for cutting molds and tools from softer materials.
- These systems use simple graphical user interfaces, which can import the STL data file, and can be set up and operated by novices in the machining area.
- Aluminum-based materials are milled out to quickly create short-run injection-mold halves without the need for numerical-control code programming or manual intervention.

Bi-Metallic Parts

- Bimetallic structures belong to a class of multi-material structures, and they potentially offer unique solutions to many engineering problems.
- Bimetallic structures of Inconel 718 and Ti6Al4V (Ti64) alloys were processed using laser engineered net shaping (LENS™).
- In LENS™ processing, an intermediate bond layer was used.
- Inconel 718 and Ti64 alloys exhibit thermal properties mismatch along with brittle intermetallic phase formation at the interface resulting in delamination.
- Compositional bond layer (CBL) is employed, which is a mixture of a third material - Vanadium Carbide - with the parent alloys to form an intermediate layer used in bonding the two immiscible alloys. A crack-free bimetallic structure of Inconel 718 and Ti64 was obtained.

Bi-Metallic Parts

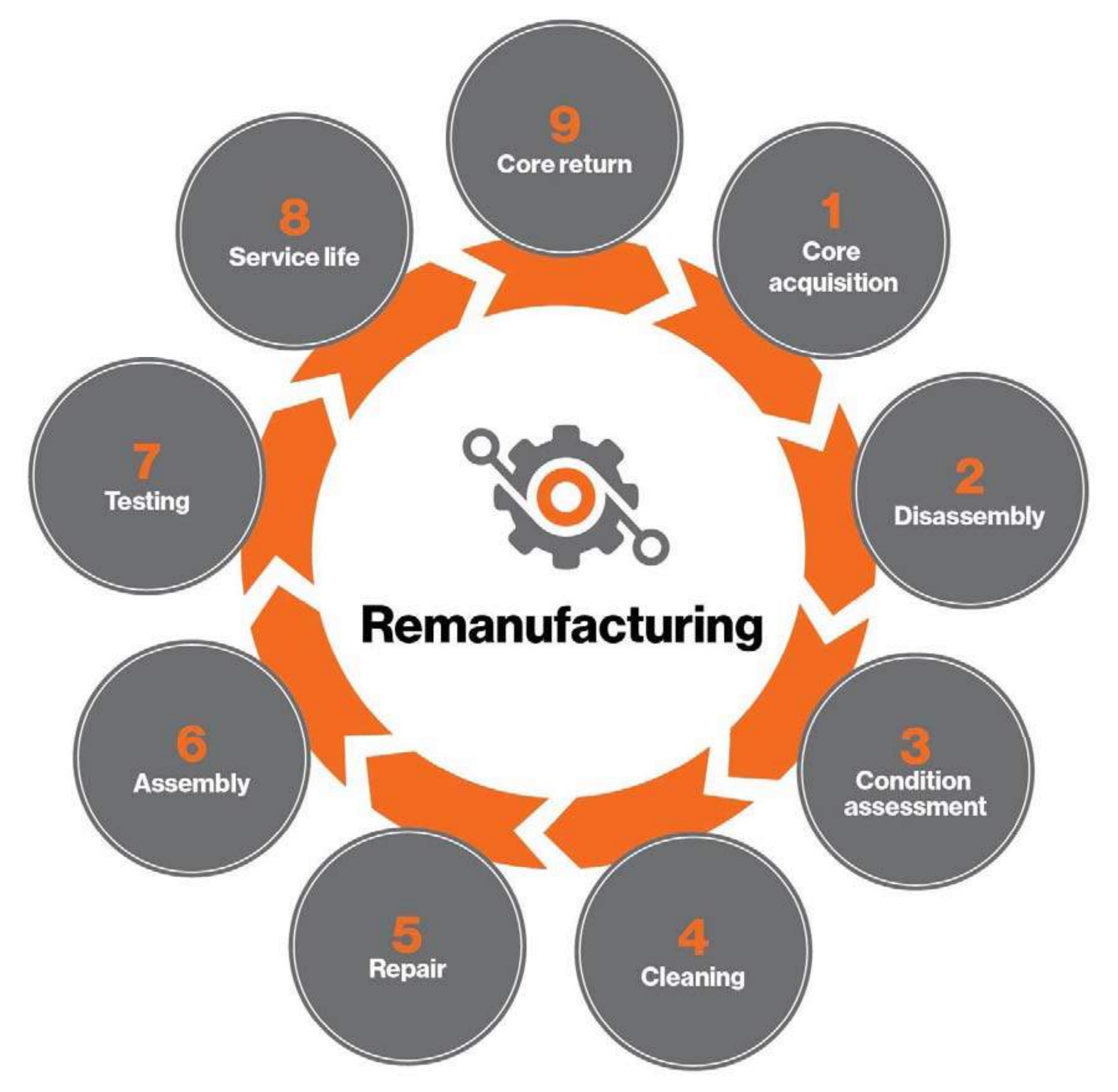




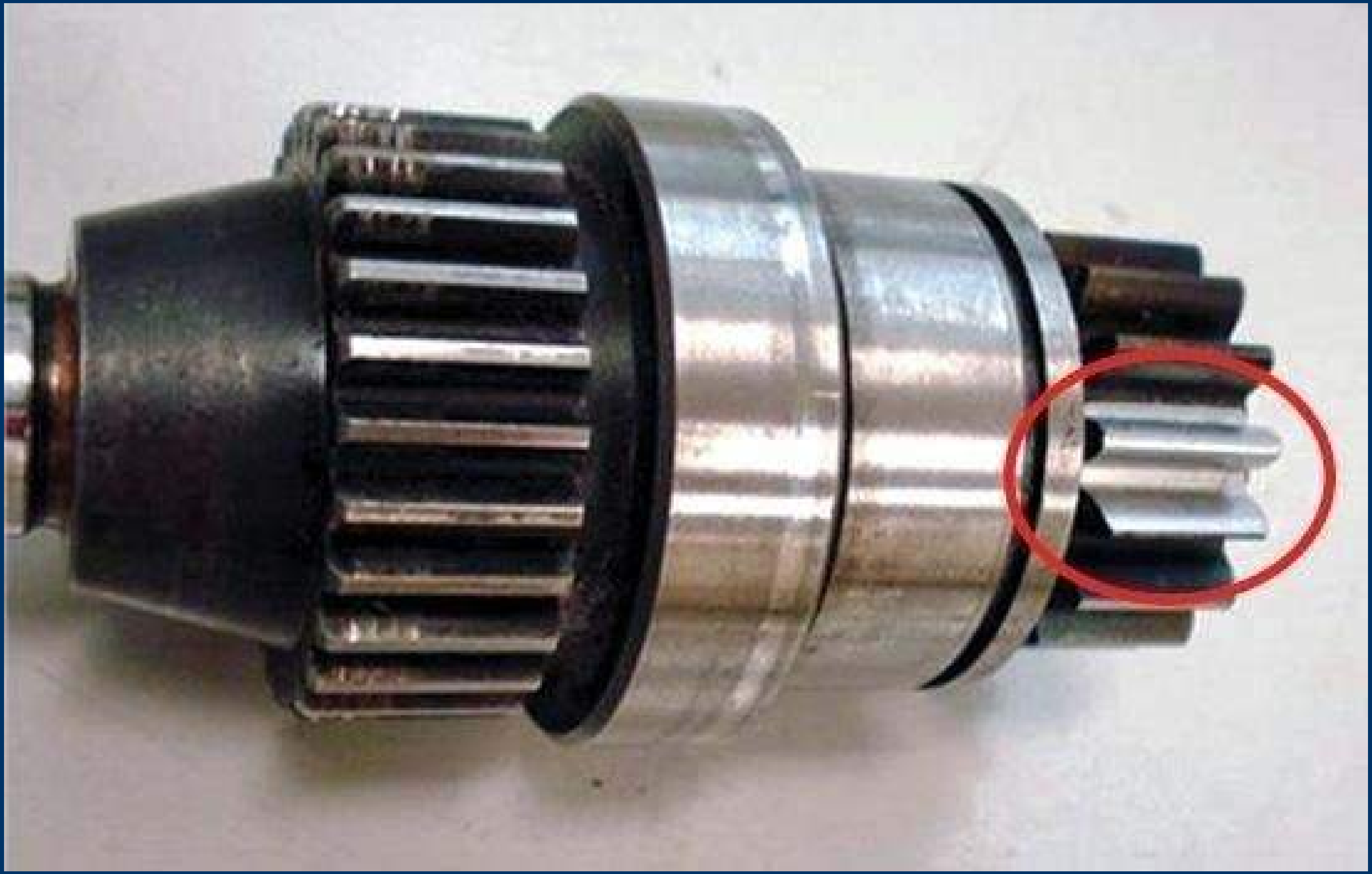
Remanufacturing

- Repair and restoration of end-of-life products are returned to as-new condition before entering the subsequent life cycle. Currently, such processes are carried out manually by skilled workers.
- AM has its potential in automated repair and restoration, thus rendering it as a more effective method for remanufacturing.
- Direct energy deposition, powder bed fusion (SLS/LENS) are suitable for this restoration of remanufacturable components.
- Challenges: geometrical complexity, geometric dimensioning and tolerancing, material compatibility, and pre-processing requirements are critical for remanufacturing

Remanufacturing



Remanufacturing



New Materials Development

- Polymers remain the leading 3D printing materials segment
- Simple plastics, like PLA and ABS, dominate the polymer market
- There is a demand for strong, functional materials, which can withstand harsh environments & high temperatures.
- The 3D printing industry is developing high-performance thermoplastics, like carbon-reinforced composites, ULTEM, PEEK and PEKK

New Materials Development…

- PEEK, PEKK are part of the polyaryletherketone family of semicrystalline polymers
- ULTEM Resin belongs to a family of amorphous thermoplastic polyetherimide (PEI)
- These parts act as functional prototypes and even end-use parts for a range of industrial applications.
- Composites are made up of a thermoplastic matrix and reinforcing fibres.
- Composites for 3D printing are reinforced with carbon fibres, glass fibres or Kevlar fibres

New Materials Development…

- Advanced materials in ceramic 3D printing are represented primarily by technical ceramics such as ***alumina*** (aluminum oxide), ***zirconia*** (zirconium oxide)
- Non-oxide and silicon-based ceramic materials such as ***silicon carbide*** and ***silicon nitride***.
- These materials offer unparalleled properties in terms of *heat resistance*, *strength* and *lightweight.* They are difficult to shape using traditional technologies.
- Which is why they are considered particularly relevant for the future of AM.

Aerospace Industry

- Prototyping Air Inlet Housing for Gas Turbine Engine
- ***Sundstrand Power Systems*** needed prototypes of an air inlet housing for a new gas turbine engine.
- They needed several fully functional prototypes to test on the development engines
- Sundstrand used DTM's SLS® system generate the necessary patterns for investment casting
- SLS was chosen because the air inlet housing has several overhanging structures from which removal of supports would have been extremely difficult.

Air Inlet Housing for Gas Turbine Engine

- Sundstrand designed several iterations of the housing as solid models on its CAD system.
- These models were converted to the STL format and sent to build the nylon evaluation models.
- After the designs were finalized, new SLS® versions of the part were created as tooling for investment casting.
- Company saved more than four months of tooling and prototyping time and saved more than US$88,000.

Air Inlet Housing for Gas Turbine Engine

Polycarbonate investment-casting pattern (right)
steel air inlet housing (**left**) for a jet turbine engine
(Courtesy DTM Corporation)

Automotive Industry

- Complex Gearbox Housing for Design Verification
- Volkswagen utilized Helysis's LOM to speed up the development of a large, complex gearbox housing for its Golf and Passat car lines.
- The CAD model for the housing was extremely complex and difficult to visualize.
- VW wanted to build a LOM part to check the design of the CAD model and then use the part for packaging studies.

Automotive Industry

- Complex Gearbox Housing for Design Verification
- Since the gearbox housing was too large for the build volume of the LOM machine the CAD model was split into five sections and reassembled after fabrication.
- It took about ten days to make and finish all five sections, and once they were completed, patternmakers glued them together to complete the final model.
- After verifying the design, the LOM model was used to develop sand-casting tooling for the creation of metal prototypes.
- Time reduced from 8 weeks to less than 2, and considerable cost savings were achieved.

Defence

- 3D printing can produce prototypes on-site for meetings, international presentations, shows, and other events.
- Logistics of defence products and components can be highly complicated due to the risks involved, restriction of movement of arms, weapons and defence equipment across international borders.
- Complex components of defence equipment can be manufactured using metal 3D printing (DMLS).
- It can be useful on the battlefield and be the difference between victory and defeat in conflict situations.

Defence

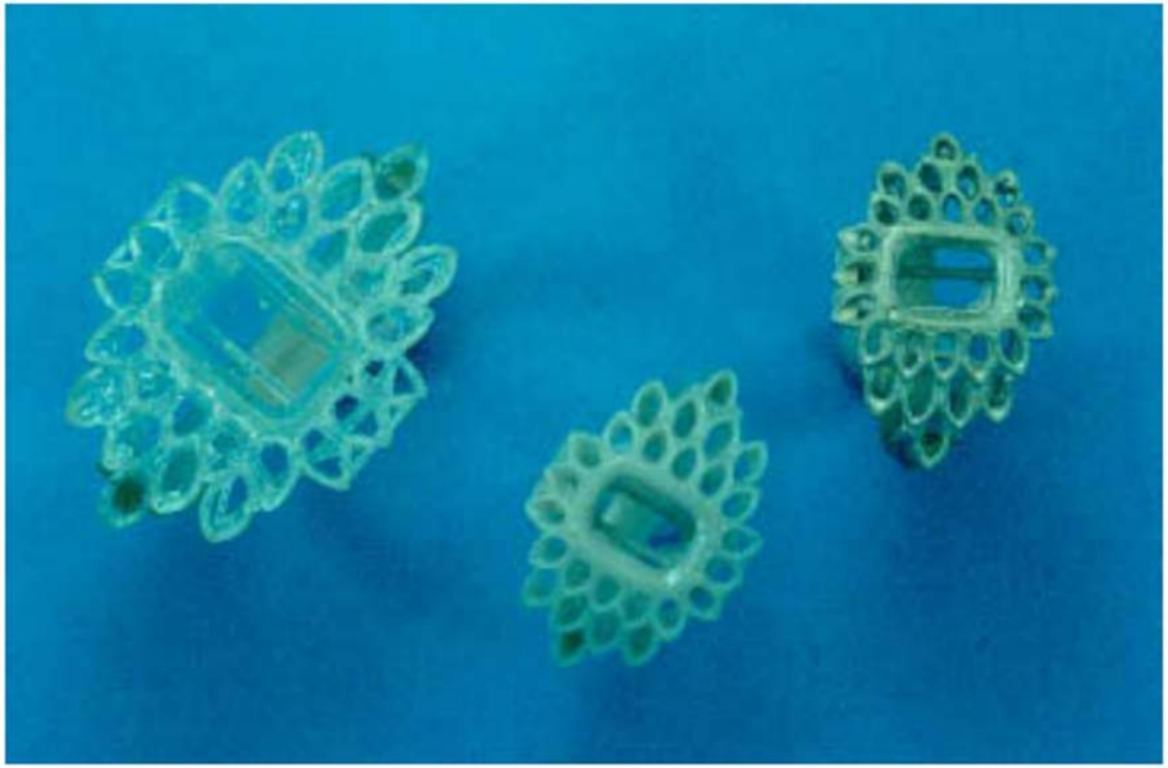
- 3DP helps to lower its cost to create prototypes.
- Defence equipment needs to undergo multiple changes and alteration before a final product can become a final product.
- 3DP or AM reduces the turnaround time and cost involved in producing these prototypes.
- AM can considerably enhance the maintenance of military systems through the production of spare or obsolete parts.

JEWELRY INDUSTRY

- Jewelry industry is heavily craft-based and automation is generally restricted
- In an experimental computer aided jewelry design and mfg system jointly developed by Nanyang Technological University and Gintic Institute of Manufacturing Technology in Singapore, the SLA (from 3D Systems) was used successfully to create fine jewelry models
- These were used as master patterns to create the rubber molds for making wax patterns that were later used in investment casting of the precious metal end product.

JEWELRY INDUSTRY

- Due to the step-wise building of the model, steps at the slope of the model were visible. With the use of better resin and finer layer thickness, this problem was reduced but not fully eliminated.
- Further processing was done using abrasive jet deburring
- The ability to create models quickly (a few hours compared to days or even weeks) and its suitability for use in the manufacturing process offer great promise in improving design and manufacture in the jewelry industry.



Two-time scaled SLA model to aid visualization (left)

Full-scale wax pattern produced from the silicon rubber molding (center)

An investment cast silver alloy prototype of a broach (right)

COIN INDUSTRY

- Mint industry is very labor-intensive and craft-based
- It relies on the skills of trained craftsmen in generating the “embossed” or relief designs on coins
- Coin manufacturing system using CAD/CAM, CNC and AM technologies developed by Nanyang Technological Univ & Gintic Institute of Mfg Technology in Singapore, the SLA (from 3D Systems) was used successfully with a Relief Creation Software to create tools for coin manufacture

COIN INDUSTRY - Steps

- Step-1: 2D artwork is read into ArtCAM
- The scanned image is reduced from a color image to a monochrome image with the fully automatic “Gray Scale” function.
- A color palette is provided for color selection and the various areas of the images are colored, either using different sizes and types of brushes or the automatic flood fill function.
- Step-2: Generate surfaces.
- The shape of a coin is generated to the required size in the CAD system for model building

COIN INDUSTRY - Steps

- A triangular mesh file is produced automatically from the 3D model.
- Step 3: Generation of the relief. In creating the 3D relief, each color in the image is assigned a shape profile.
- Step 4: wrapping of the 3D relief onto the coin surface.
- The two sets of triangular mesh files, of the relief and the coin shape, are automatically combined.
- The resultant model file can be color shaded and used by the SLA to build the prototype

COIN INDUSTRY - Steps

- Step 5: convert the triangular mesh files into the STL file format.
- After the conversion, the STL file is sent to the SLA to create the 3D coin pattern which will be used for proofing of design

COIN INDUSTRY - Steps

Two-dimensional artwork of a series of Chinese characters and a roaring dragon

Three-dimensional relief of artwork of the roaring dragon

TABLEWARE INDUSTRY

- CAD and AM technologies are used in an integrated system to create better designs in a faster and more accurate manner.
- Methodology used is similar to that used in the jewelry and coin industries.

Steps:

(1) Scanning of the 2D artwork.

(2) Generation of surfaces.

(3) Generation of 3D decoration reliefs.

(4) Wrapping of reliefs on surfaces.

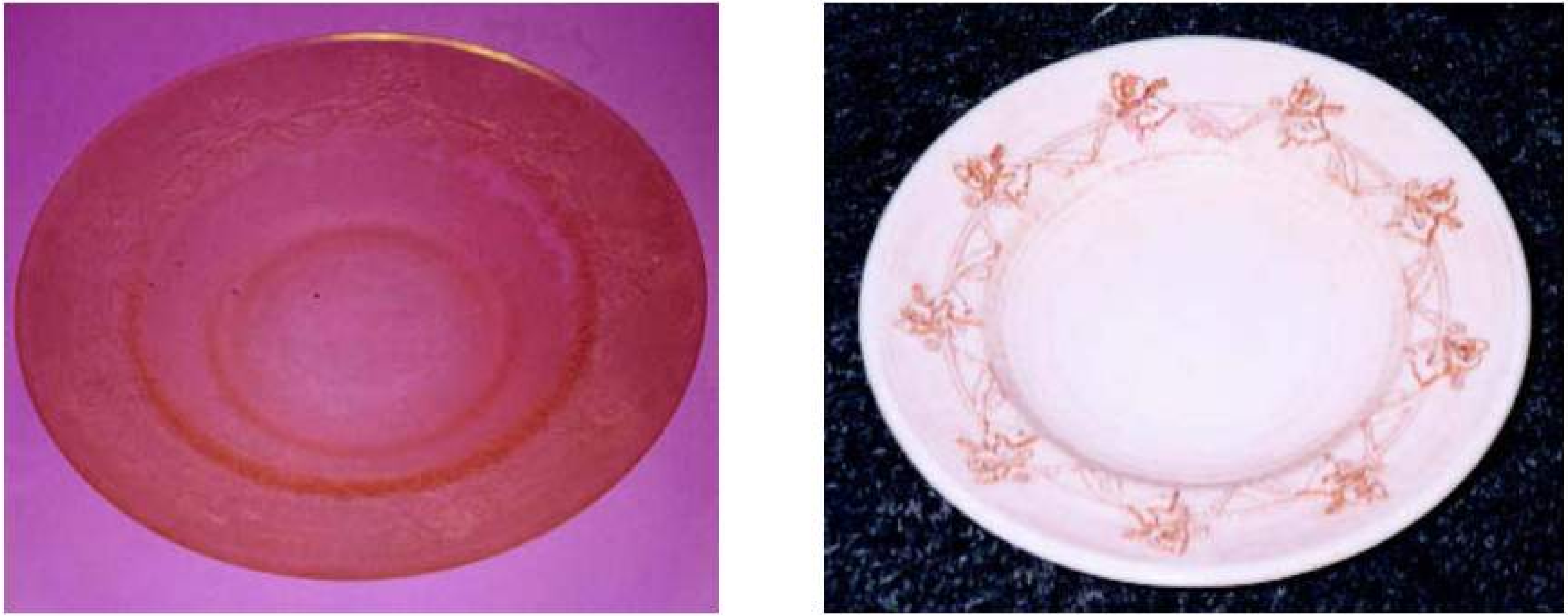
(5) Converting triangular mesh files to STL file.

(6) Building of model by the RP system.

TABLEWARE INDUSTRY

- 3D Systems’ SLA & Helysis’ LOM are experimented
- AM system saves time in designing and developing tableware, particularly in building a physical prototype.
- It can also improve designs by simply amending the CAD model and the overall system is easy and friendly to use.

TABLEWARE INDUSTRY



Dinner plate prototype built using SLA (left) and LOM (right)

TABLEWARE INDUSTRY

LOM model of a tea pot

(Courtesy of Champion Machine Tools, Singapore)

End of Unit - 5