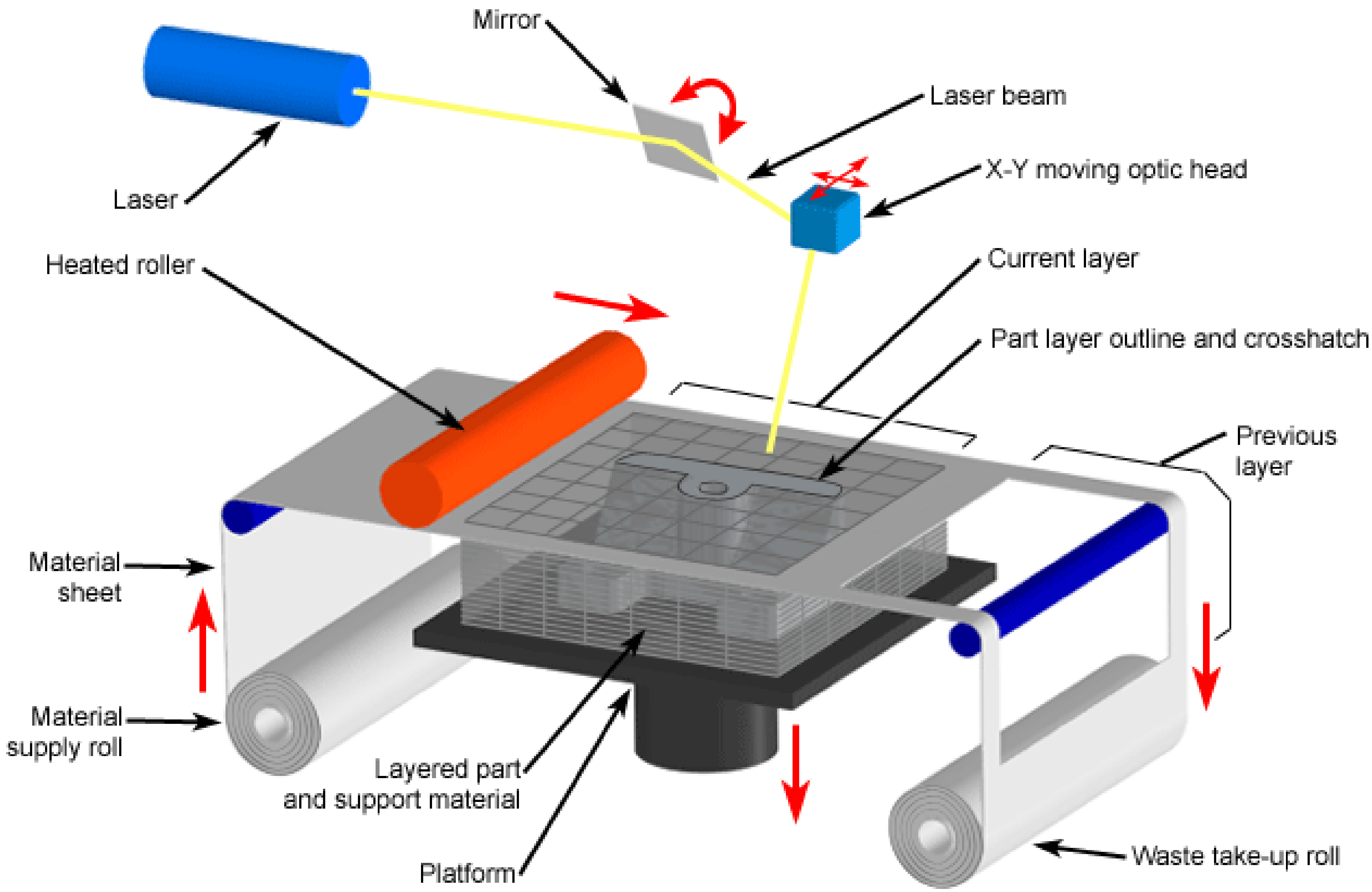
# Laminated Object Manufacturing (LOM)

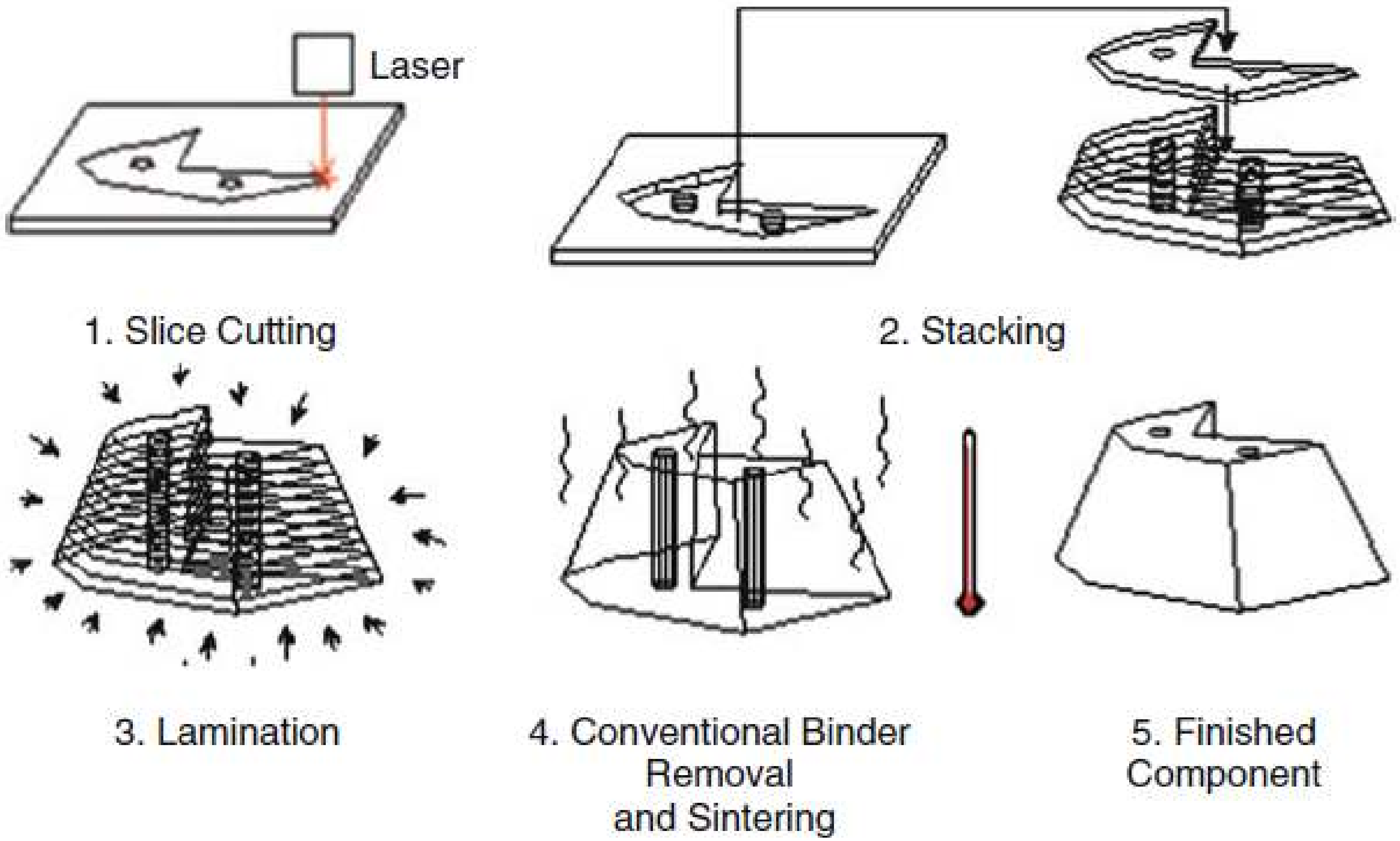
Solid physical model made by stacking layers of sheet stock, each an outline of the cross-sectional shape of a CAD model that is sliced into layers

- Starting sheet stock includes paper, plastic, cellulose, metals, or fiber-reinforced materials
- The sheet is usually supplied with adhesive backing as rolls that are spooled between two reels
- After cutting, excess material in the layer remains in place to support the part during building

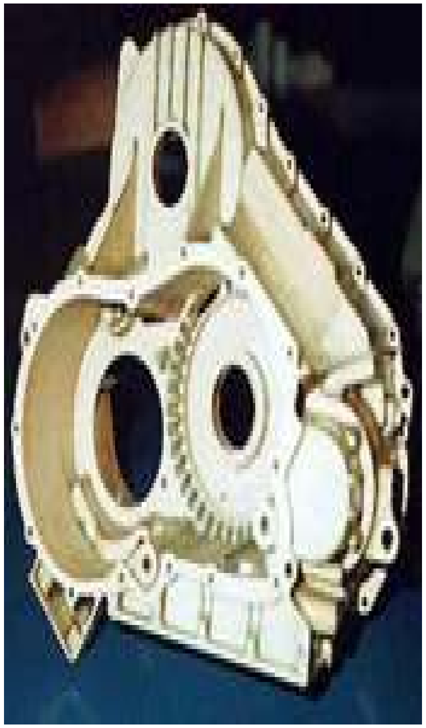
# Laminated Object Manufacturing



# CAM-LEM


Laser
1. Slice Cutting
2. Stacking
3. Lamination
4. Conventional Binder Removal and Sintering
5. Finished Component

# LOM Examples



# Advantages

- Ability to produce larger-scaled models
- Uses very inexpensive paper
- Fast and accurate
- Good handling strength
- Environmentally friendly
- Not health threatening

# Disadvantages

- Need for decubing, which requires a lot of labor
- Can be a fire hazard
- finish, accuracy and stability of paper objects not as good as materials used with other RP methods

# Typical Uses

- Investment casting patterns
- Concept verification
- Masters for silicone-rubber injection tools
- Fit-check
- Direct use

# Extrusion Based Additive Manufacturing

- These technologies can be visualized as similar to cake icing, in that material contained in a reservoir is forced out through a nozzle when pressure is applied.

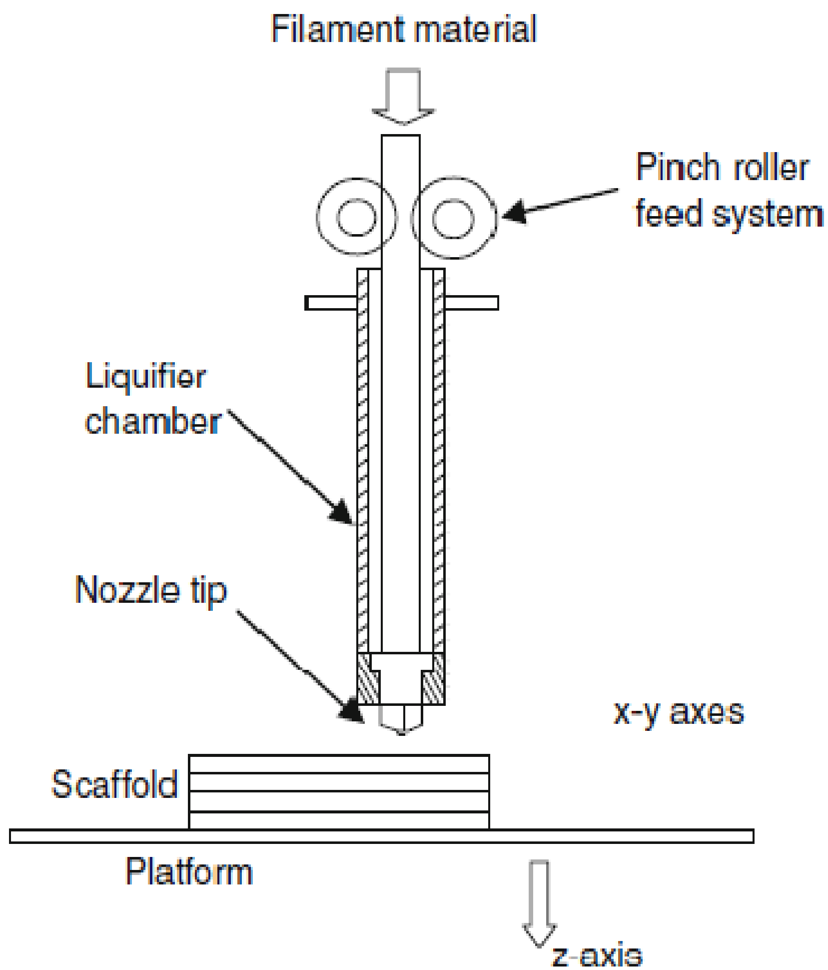
- The material that is being extruded must be in a semi-solid state when it comes out of the nozzle.

- The material must fully solidify while remaining in that shape.

- The material must bond to material that has already been extruded so that a solid structure can result.

# Key Features

- Loading of material;
- Liquification of the material;
- Application of pressure to move the material through the nozzle;
- Extrusion;
- Plotting according to a predefined path and in a controlled manner;
- Bonding of the material to itself or secondary build materials to form a coherent solid structure;
- Inclusion of support structures to enable complex geometrical features.




Schematic of extrusion-based systems

# Key features Contd…

- We would like to have material in semi solid state but handling cost & capability is more, so we have material in form of pallets i.e. solid.

- The material inside the chamber should be kept in a molten state but care should be taken to maintain it at as low a temperature as possible since some polymers degrade quickly at higher temperatures and could also burn, leaving residue on the inside of the chamber that would be difficult to remove and that would contaminate further melt.

- Shape and size of extruded part is governed by nozzle.

- Minimum feature size is based on diameter of nozzle.

# Extrusion

- Mass Flow is related to

a) Pressure drop between chamber and surrounding atmosphere

b) Nozzle geometry

c) Material viscosity

# Solidification

- Once the material is extruded, it should ideally remain the same shape and size.
- **Gravity and surface tension**, however, may cause the material to change shape.
- Size may vary according to cooling and drying effects.
- The cooling is also very likely to be nonlinear, then it is possible the resulting part will distort upon cooling.
- This can be minimized by use of a controlled environmental chamber when building the part.

# Positional Control

- Extrusion-based systems use a platform that indexes in the vertical direction to allow formation of individual layers.
- The extrusion head is typically carried on a plotting system that allows movement in the horizontal plane.
- Plotting must be coordinated with the extrusion rate to ensure smooth and consistent deposition.
- Since the requirement is to move a mechanical extrusion head in the horizontal plane then the most appropriate mechanism to use would be a standard planar plotting system. For example belt drives or lead-screws.

# Bonding

- For heat-based systems there must be sufficient residual heat energy to activate the surfaces of the adjacent regions, causing bonding.
- Gel-based systems must contain residual solvent or wetting agent in the extruded filament to ensure the new material will bond to the adjacent regions that have already been deposited.
- If there is insufficient energy, the regions may adhere, but there would be a distinct boundary between new and previously deposited material.
- This can represent a fracture surface where the materials can be easily separated.
- Too much energy may cause the previously deposited material to flow, which in turn may result in a poorly defined part.

# Support Generation

- Supports in such systems take two general forms:
  - Similar material supports
  - Secondary material supports
- The most effective way to remove supports from the part is to fabricate them in a different material.

- The variation in material properties can be exploited so that supports are easily distinguishable from part material, either visually (e.g., using a different color material), mechanically (e.g., using a weaker material for the supports), or chemically (e.g., using a material that can be removed using a solvent without affecting the part material).

- To do this, the extrusion-based equipment should have a second extruder. In this way, the secondary material can be prepared with the correct build parameters and extruded in parallel with the current layer of build material, without delay.

# Plotting and Path Control

- Extrusion-based machines take input from CAD systems using the generic STL file format.
- This file format enables easy extraction of the slice profile, giving the outline of each slice.
- Part accuracy is maintained by plotting the outline material first, which will then act as a constraining region for the fill material.
- Determining the fill pattern for the interior of the outlines is a much more difficult task for the control software.

# Control of Extrusion

Precise control of extrusion is a complex trade-off, dependent on a significant number of parameters, including:

– **Input pressure:** This variable is changed regularly during a build, as it is tightly coupled with other input control parameters. Changing the input pressure (or force applied to the material) results in a corresponding output flow rate change.

– **Temperature:** Maintaining a constant temperature within the melt inside the chamber would be the ideal situation. However, small fluctuations are inevitable and will cause changes in the flow characteristics.

– **Nozzle diameter:** This is constant for a particular build, but many extrusion based systems do allow for interchangeable nozzles that can be used to offset speed against precision.

– **Material characteristics:** This would include viscosity information that would help in understanding the material flow through the nozzle. Since viscous flow, creep, etc. are very difficult to predict, accurately starting and stopping flow can be difficult.

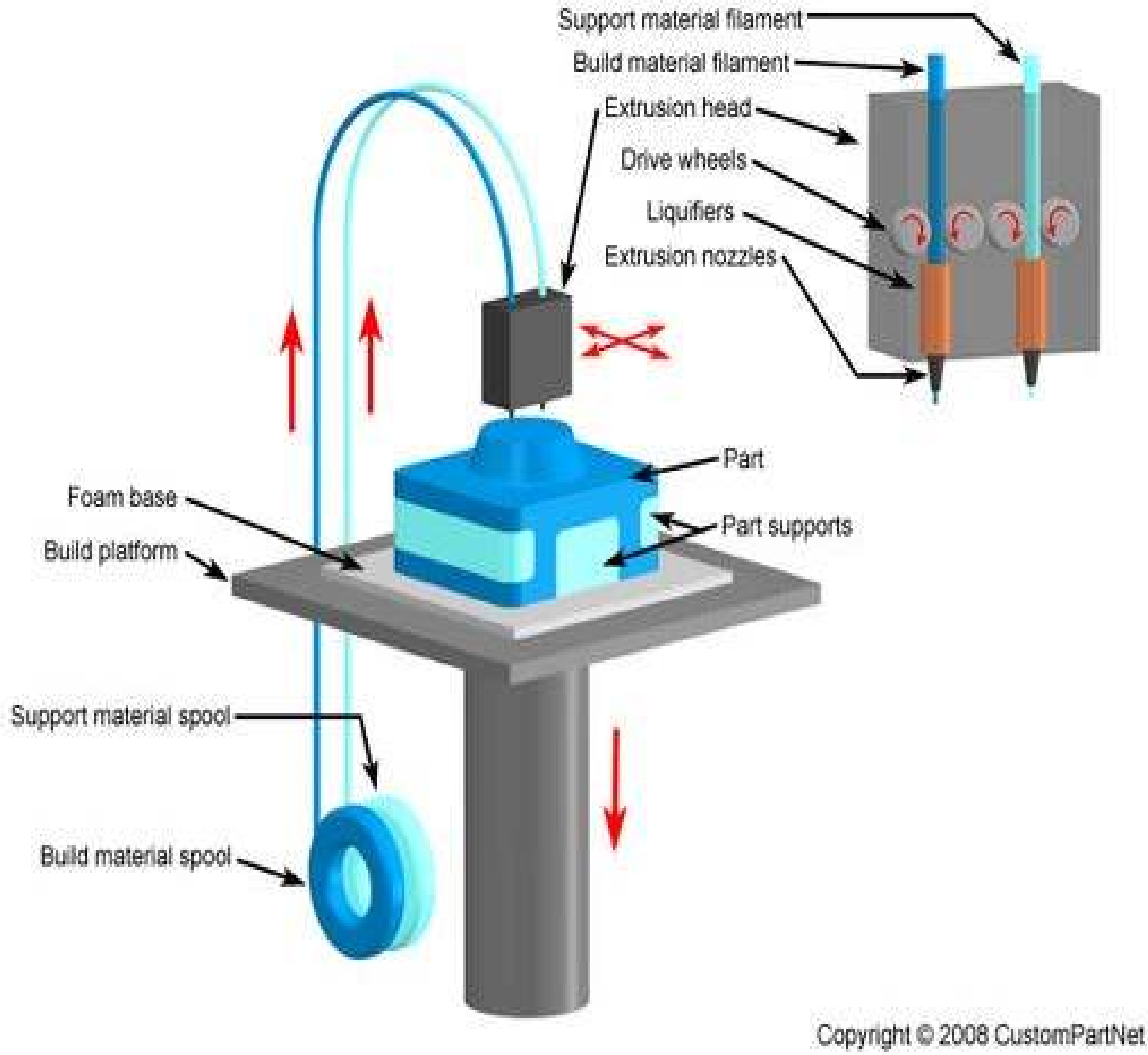
# Control of Extrusion Contd…

– **Gravity and other factors:** If no pressure is applied to the chamber, it is possible that material will still flow due to the mass of the molten material within the chamber causing a pressure head. Surface tension of the melt and drag forces at the internal surfaces of the nozzle may retard this effect.

– **Temperature build up within the part:** All parts will start to cool down as soon as the material has been extruded. However, different geometries will cool at different rates. Large, massive structures will hold their heat for longer times than smaller, thinner parts, due to the variation in surface to volume ratio.

# Fused Deposition Modeling

- Fused Deposition Modeling (FDM), produced and developed by Stratasys, USA.
- FDM uses a heating chamber to liquefy polymer that is fed into the system as a filament.
- The filament is pushed into the chamber by a tractor wheel arrangement and it is this pushing that generates the extrusion pressure.
- The major strength of FDM is in the range of materials and the effective mechanical properties of resulting parts made using this technology.
- Parts made using FDM are amongst the strongest for any polymer-based additive manufacturing process.


Support material filament
Build material filament
Extrusion head
Drive wheels
Liquifiers
Extrusion nozzles
Part
Part supports
Foam base
Build platform
Support material spool
Build material spool
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# Materials

- ❖ The most popular material is the ABSplus material, which can be used on all current Stratasys FDM machines.
- ❖ Some machines also have an option for ABS blended with Polycarbonate.

| Property | ABS | ABSi | ABSplus | ABS/PC |
|---|---|---|---|---|
| Tensile strength | 22 MPa | 37 MPa | 36 MPa | 34.8 MPa |
| Tensile modulus | 1,627 MPa | 1,915 MPa | 2,265 MPa | 1,827 MPa |
| Elongation | 6% | 3.1% | 4% | 4.3% |
| Flexural strength | 41 MPa | 61 MPa | 52 MPa | 50 MPa |
| Flexural modulus | 1,834 MPa | 1,820 MPa | 2,198 MPa | 1,863 MPa |
| IZOD impact | 106.78 J/m$^2$ | 101.4 J/m$^2$ | 96 J/m$^2$ | 123 J/m$^2$ |
| Heat deflection @ 66 psi | 90°C | 87°C | 96°C | 110°C |
| Heat deflection @ 264 psi | 76°C | 73°C | 82°C | 96°C |
| Thermal expansion | 5.60E-05 in/in/F | 6.7E-6 in/in/F | 4.90E-05 in/in/F | 4.10E-5 in/in F |
| Specific gravity | 1.05 | 1.08 | 1.04 | 1.2 |

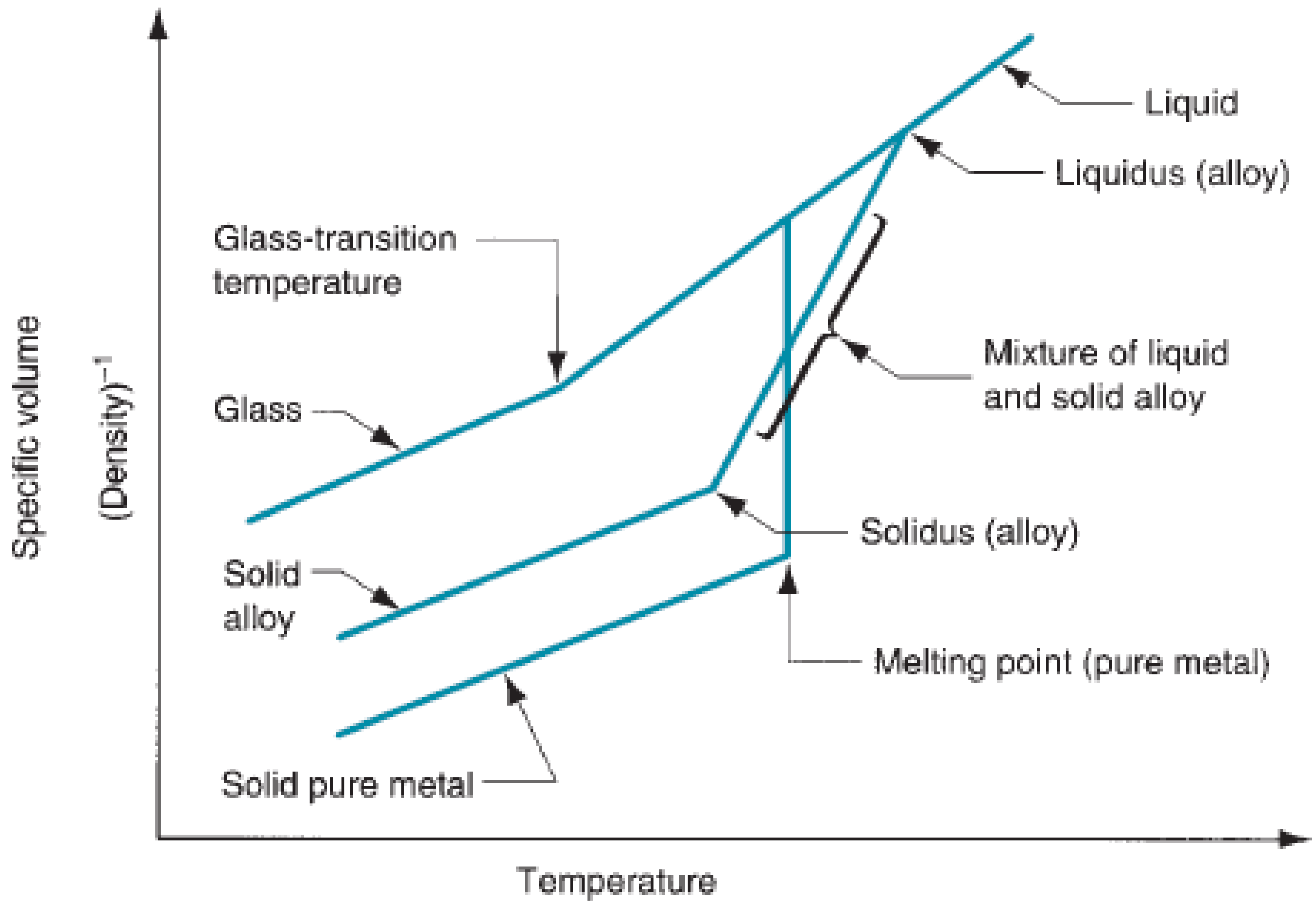
# Materials Contd…

- Note that FDM works best with polymers that are amorphous in nature rather than the highly crystalline polymers.
- This is because the polymers that work best are those that are extruded in a viscous paste rather than in a lower viscosity form.
- As in amorphous polymers, there is no distinct melting point and the material increasingly softens and viscosity lowers with increasing temperature.
- The viscosity at which these amorphous polymers can be extruded under pressure is high enough that their shape will be largely maintained after extrusion, maintaining the extrusion shape and enabling them to solidify quickly and easily.

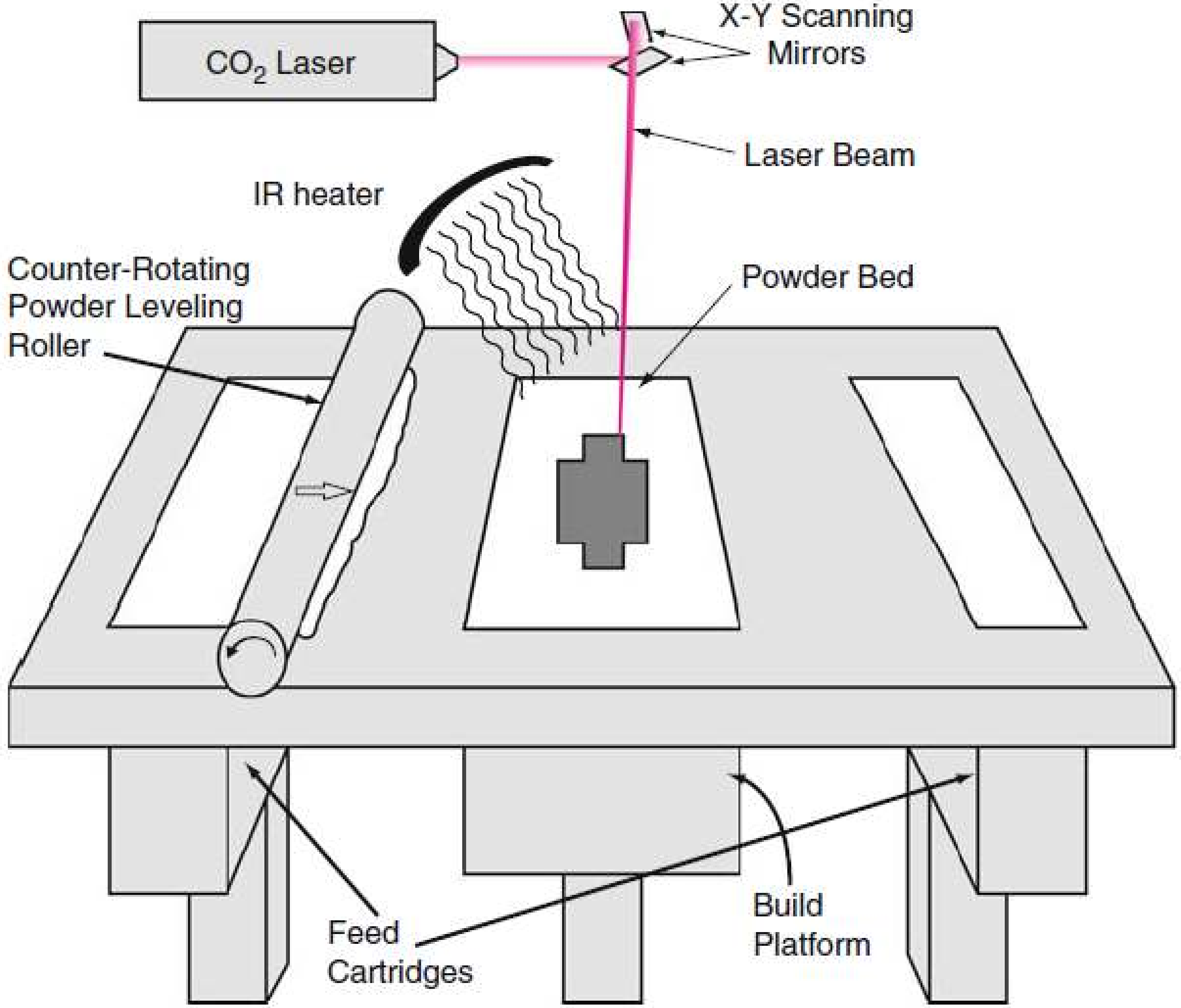
# Limitations of FDM

- Sharp features or corners not possible to get;
- Part strength is weak perpendicular to build axis;
- More area in slices requires longer build times;
- Temperature fluctuations during production could lead to delamination.

# Thermal Expansion Characteristics



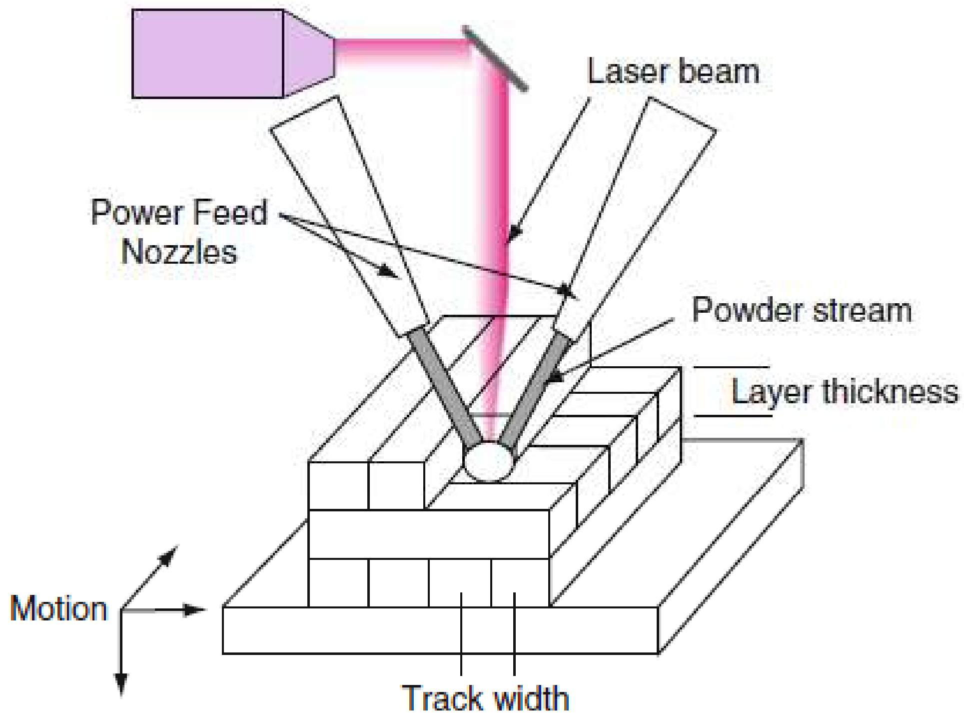
# Selective Laser Sintering



# Selective Laser Sintering

- Layer thickness: ~0.1 mm thick;
- The part building takes place inside an enclosed chamber filled with nitrogen gas to minimize oxidation and degradation of the powdered material;
- The powder in the building platform is maintained at an elevated temperature just below the melting point and/or glass transition temperature of the powdered material;
- Infrared heaters are used to maintain an elevated temperature around the part being formed;
- A focused $CO_2$ laser beam is moved on the bed in such a way that it thermally fuses the material to form the slice cross-section;
- Surrounding powders remain loose and serve as support for subsequent layers.

# Beam Deposition Processes




- BD processes are NOT used to melt a material that is pre-laid in a powder bed but are used to melt materials as they are being deposited;
- BD processes use a focused heat source (such as a laser, electron beam or plasma arc) to melt the material and build-up 3D objects in a manner similar to extrusion-based process;