

VIBE PROJECT

Virtual Biomedical and STEM/STEAM Education

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VIBE

PROJECT

3D VISUALISATION & PRINTING

CLASSIFYING PRINTING
TECHNOLOGIES

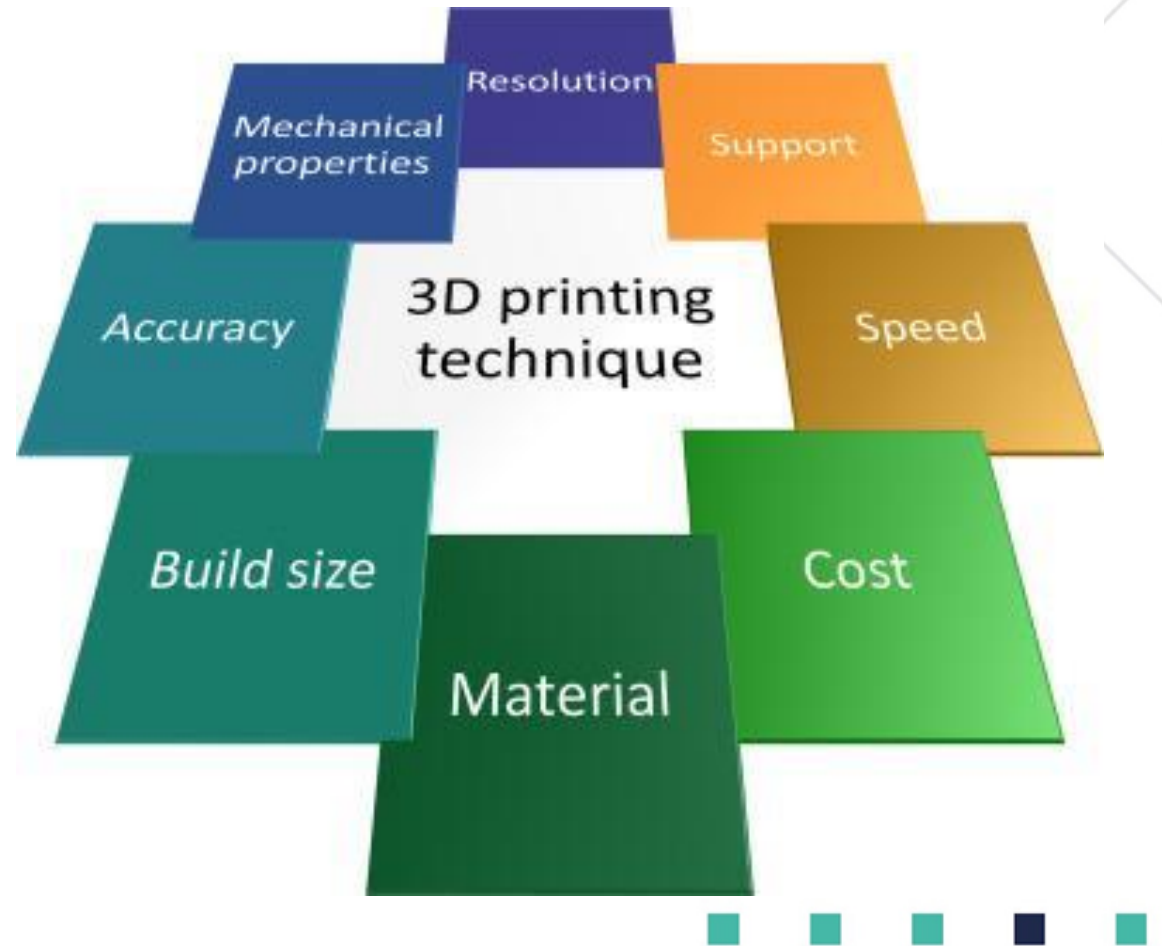
FDM printing



➤➤➤ Process of printing

•In additive production, **various processes**, machines and raw materials are used to produce a three-dimensional object. Although each of them are classified under the same manufacturing technology, there are some **key differences** between **processes** and applied raw **materials**.

•Some of the physical transformations used in 3D printing uses **melt extrusion**, **UV polymerization**, **continuous liquid interface production** and **sintering**.





Types of 3D printing processes

1. Material Extrusion

- FDM or FFF (Fused Deposition Modelling)
CFF (Composite Filament Fabrication)

2. Vat polymerization

- SLA (Stereolithography)
- CLIP (Continuous Liquid Interface Production)
- DLP (Digital Light Processing)

3. Powder bed fusion (polymers)

- SLS (Selective Laser Sintering)

4. Material Jetting

- DOD (Drop On Demand)

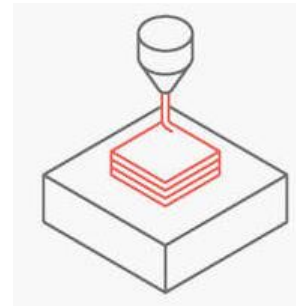
5. Binder Jetting

6. Powder bed fusion (metals)

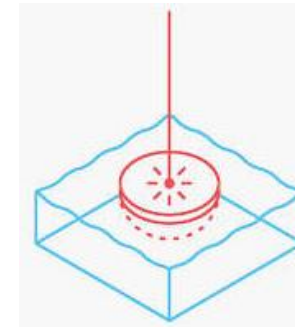
- DMLS (Direct Metal Laser Sintering)
- SLM (Selective Laser Melting)
- EBM (Electron-Beam Melting)

7. Laminated

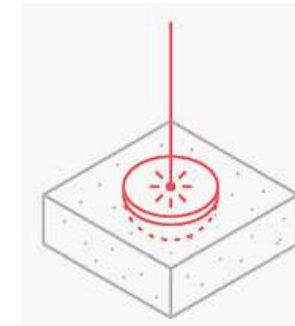
- LOM (Laminated Object Manufacturing)



FDM



SLA



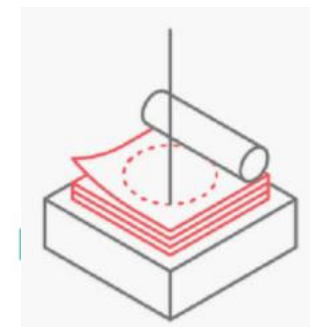
SLS



DOD



Binder Jetting



LOM



Applied materials

1. Material Extrusion

- FDM or FFF Thermoplastic polymers, metal alloys, edible materials, rubbers, plasticine
- CFF Nylon (with carbon fibers), Kevlar, glass

2. Vat polymerization

- SLA, DLP, CLIP Photopolymers

3. Powder bed fusion (polymers)

- SLS Thermoplastic polyamide, metal-, ceramic powders

4. Material Jetting

- DOD Hot molten materials (wax, thermoplastic polymers, metal alloys)

5. Binder Jetting Ceramic-based powders or metals, binder is water

6. Powder bed fusion (metals)

- DMLS, EBM Almost any metal alloy
- SLM Titanium alloys, cobalt chromium alloy, Stainless steel, aluminum

7. Laminated

- LOM Paper, metal foils, plastic films





Material classification

1. Polymers
 - Thermoplastic
 - **Filaments** (FDM)
 - **Polyamides** (SLS)
 - Heat-curing
 - **Resins** (SLA, DLP, Material jetting)
2. Metals
 - **Metal powder** (DMLS, SLM, Binder Jetting)
3. Other
 - Metal wire (FDM)
 - Filament composites (FDM)
 - Sand (Binder Jetting)
 - Chocolate (FDM)
 - Concrete (FDM)
 - Clay-ceramics (FDM)



FDM filament roll, SLS nylon powder, SLA resin



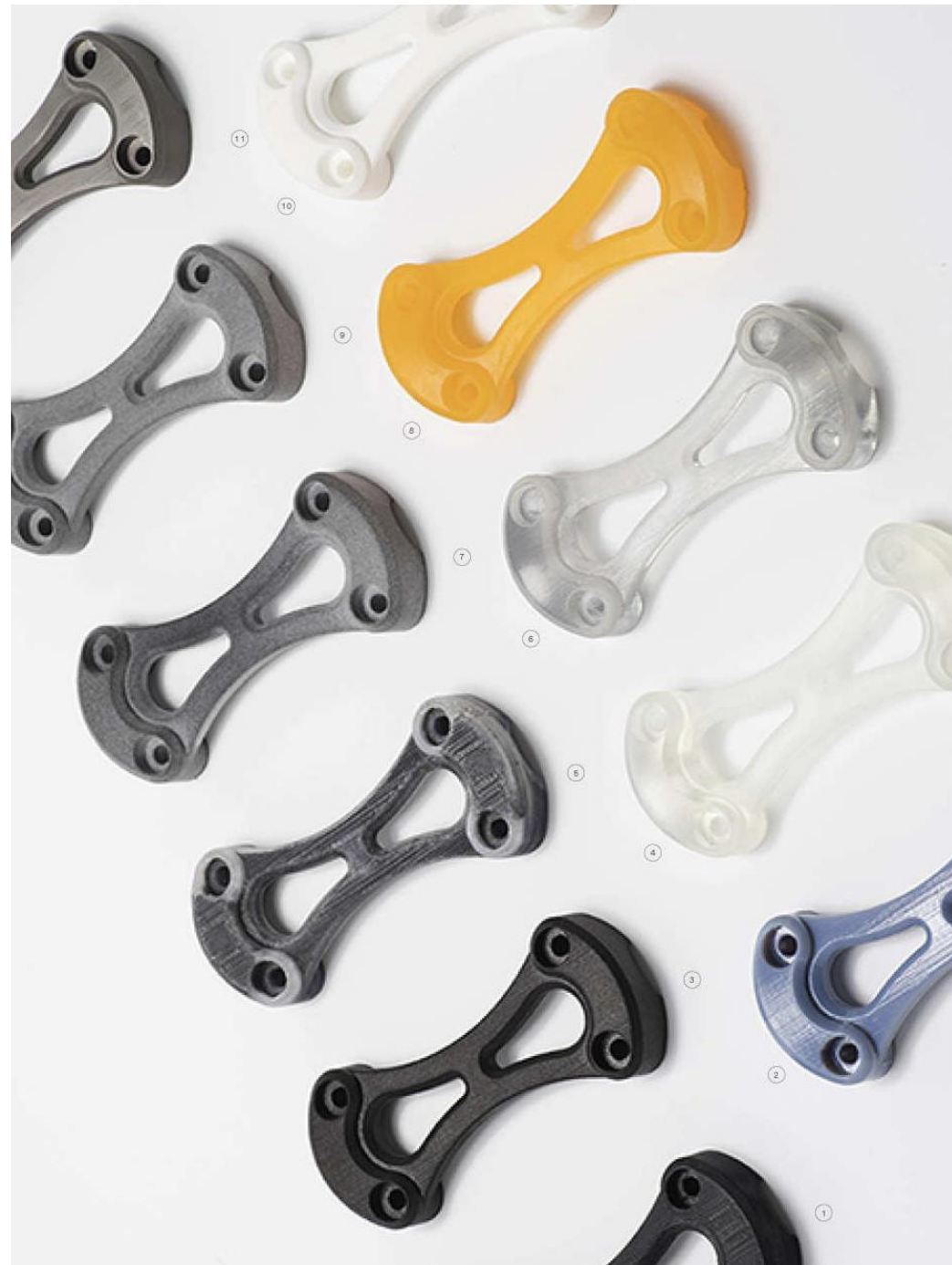


	Print Temp	Bed Temp	Strength	Flexibility	Durability	Difficulty	Shrinkage	Soluble	Food Safe	Blue Tape	Blue Stick	Typical Uses
ABS Acrylonitrile Butadiene Styrene	210-230	10-100	●●●	●●●	●●●	●●●	●●●	Acetone	No	●	●	Functional Parts
ASA Acrylonitrile Styrene Acrylate	240-260	100-120	●●●	●●●	●●●	●●●	●●●	Acetone	No	●	●	Outdoor Use
Carbon Fiber Carbon Fiber and PLA blend	190-220	N/A	●●●	●●●	●●●	●●●	●●●	No	No	●	—	Functional Parts
Cleaning Cleaning Filament	150-200	N/A	—	—	—	●	—	—	—	—	—	Nozzle Cleaning / Unclogging
Color Changing PLA or ABS with color changing properties	210-220	N/A	●●●	●●●	●●●	●●●	●●●	No	No	●	●	Educational, Modelling
Conductive Conductive PLA or ABS	210-220	N/A	●●●	●●●	●●●	●●●	●●●	No	No	●	—	Electronics
Flexible, TPE, TPU Thermoplastic Urethane / Polyurethane	210-220	N/A	●	●●●	●●●	●●●	●●●	No	No	●	●	Elastic Parts, Wearables
FPE Flexible Polycarbonate	260-280	75	●	●●●	●●●	●●●	●●●	No	Yes	—	—	Flexible Parts
Glow-In-The-Dark Glow in the dark PLA or ABS	210-220	N/A	●●●	●●●	●●●	●●●	●●●	No	No	●	—	Educational, Modelling
HIPS High Impact Polystyrene	210-230	10-100	●	●●●	●●●	●●●	●●●	Solvent	No	●	●	Support Structures
Lignin (bioFila) Lignin and PLA plus additives	180-200	N/A	●●●	●	●●●	●●●	●●●	No	Yes	●	●	All Purpose
Magnetic PLA with powdered iron	190-220	N/A	●●●	●●●	●●●	●●●	●●●	No	No	●	—	Educational, Experimental
Metal PLA / ABS Metal Powder and PLA or ABS blend	190-220	N/A	●●●	●	●●●	●●●	●●●	No	No	●	—	Jewelry
nGen Similar to PETG	210-240	N/A	●●●	●●●	●●●	●●●	●●●	No	Yes	●	—	All Purpose
Nylon Polyamide	250-280	50-100	●●●	●●●	●●●	●●●	●●●	No	Yes	—	—	All Purpose
PC Polycarbonate	270-310	10-100	●●●	●●●	●●●	●●●	●●●	Acetone	No	—	—	Functional Parts
PC/ABS Polycarbonate/ABS	260-280	1-50	●●●	●	●●●	●●●	●●●	No	No	—	—	Functional Parts
PET (CPE) Polyethylene Terephthalate	230-250	N/A	●●●	●●●	●●●	●●●	●●●	No	Yes	●	—	All Purpose
PETG (XT, N-Vent) Polyethylene Terephthalate Glycol	230-250	N/A	●●●	●●●	●●●	●●●	●●●	No	Yes	●	—	All Purpose
PETT (T-Glase) Polyethylene terephthalate	210-240	N/A	●●●	●●●	●●●	●●●	●●●	No	Yes	●	—	Functional Parts
PLA Polylactic Acid	180-230	N/A	●●●	●	●●●	●●●	●●●	No	Yes	●	●	Consumer Products
PMMA, Acrylic Polymethyl Methacrylate	230-250	100-130	●●●	●	●●●	●●●	●●●	Acetone	No	●	●	Light diffusers, Modelling
POM, Acetal Polycyanoethylene	210-230	1-50	●●●	●	●●●	●●●	●●●	Chemical	No	—	—	Functional Parts
PORO-LAY Rubber-elastomeric polymer with PVA	220-230	N/A	●●●	●	●●●	●●●	●●●	Water	Yes	●	—	Experimental
PP Polypropylene	210-230	20-250	●●●	●●●	●●●	●●●	●●●	No	Yes	●	—	Flexible Components
PVA Polyvinyl Alcohol	180-190	N/A	●●●	●	●●●	●●●	●●●	Water	Yes	●	—	Support Structures
Sandstone (Laybrick) Co-polyester and chalk powder	180-220	N/A	●	●	●	●	●	No	No	●	—	Architectural Modelling
TPC Thermoplastic Copolyester	210-230	60-100	●	●●●	●●●	●●●	●●●	No	No	●	—	Elastic Parts, Outdoor Use
Wax (MOLDLAY) Wax-like properties	170-180	N/A	●	●	●	●	●	No	No	●	—	Lost Wax Casting
Wood (Laywood) Wood PLA Blend	180-220	N/A	●●●	●●●	●●●	●●●	●●●	No	No	●	—	All Purpose (natural finish)





1. ABS (FDM)
2. Rigid opaque resin (Material Jetting)
3. Graphite-reinforced nylon (SLS)
4. Transparent resin (SLA)
5. Carbon-reinforced nylon (CFF)
6. Ultra clear resin (Material Jetting)
7. HP nylon (Multi Jet Fusion)
8. Castable resin (DLP)
9. Grey PA12 nylon (SLS)
10. White PA12 nylon (SLS)
11. Tool steel (DMLS)

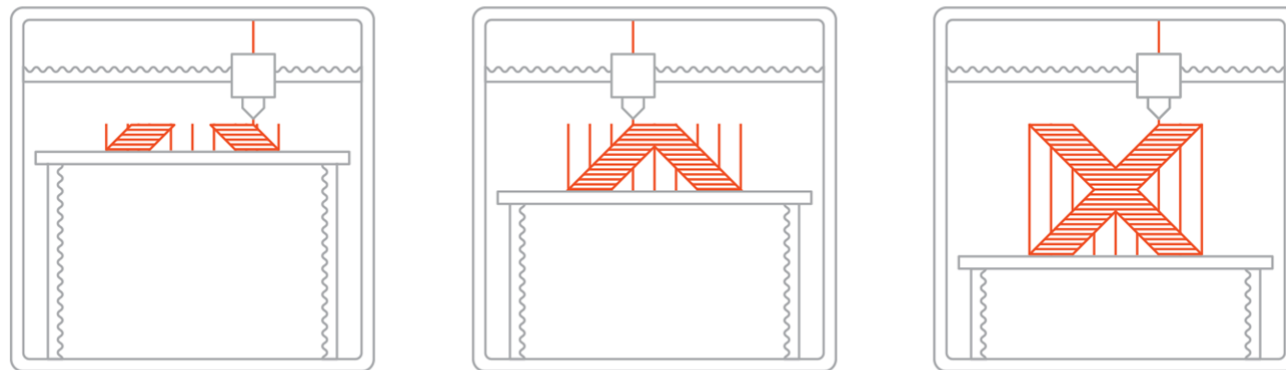




Material extrusion FDM/FFF, CFF

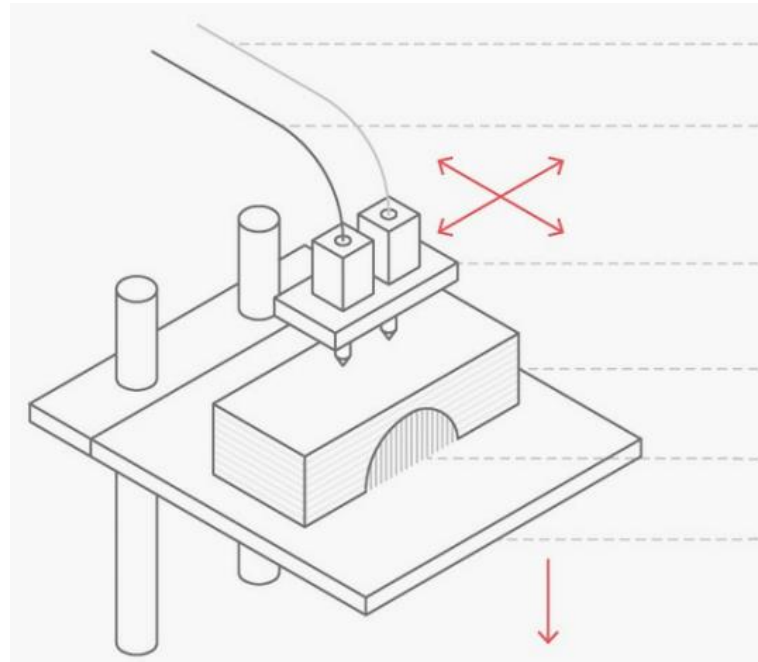
When extruding the substance, it prints from a **solid thermoplastic fiber material** (filament), which passes through a **heated nozzle**. The printer places the material on a **building platform** on a predetermined route where the filament is **cools and solidifies** to form a solid object.

[FDM printing - video](#)





Material extrusion FDM/FFF, CFF



Support filament

Part filament

Extrusion head

Part

Support material

Build platform

- **Materials:** thermoplastic filament (PLA, ABS, PET, PETG, TPU).
- **Accuracy:** $\pm 0.5\%$ (lower limit ± 0.5 mm)
- **Application:** Equipment for houses, shape and fit testing, simpler use objects.
- **Advantages:** cheap, most widespread, plenty of materials and color choices.
- **Weakness:** Fragile, not suitable for mechanical components. Certain sizes are more expensive than SLS.





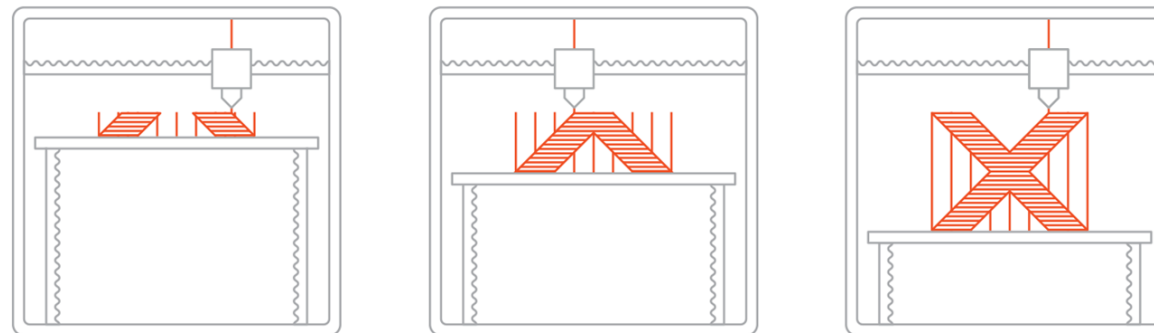
Material extrusion FDM/FFF, CFF

The filament roll **continuously dispenses** into the 3D printer and feeded into the **printer nozzle** in the extrusion head. The printer nozzle is heated to the desired temperature, then a motor pushes the filament on the heated nozzle where it **melts**.

Then, the printer moves the extruder head along the **specified coordinates**, placing the **molten material on the building plate** where it cools down and **solidifies**.

As soon as a layer is completed, the printer starts **another layer**. The process of printing cross-sections **repeats this process per layer** until the object is completely made.

Depending on the geometry of the object, it is sometimes necessary to **add support structures**, for example, if a model has steep **overhang parts**.





Properties of material extrusion

Many **parameters can be set** on most FDM machines for accurate printing. **Speed of construction, extrusion speed** and **nozzle temperature**, etc. (some machines use automatic settings based on the type of printed material).

Basically, the **diameter of the nozzle** and the **height of the layer** determines the **resolution** of the printed object. While all parameters determine the size accuracy of the component, the **smaller nozzle diameter** and the lower **layer height** usually means a solution for components where a **smoother surface** and **greater detail** are required.

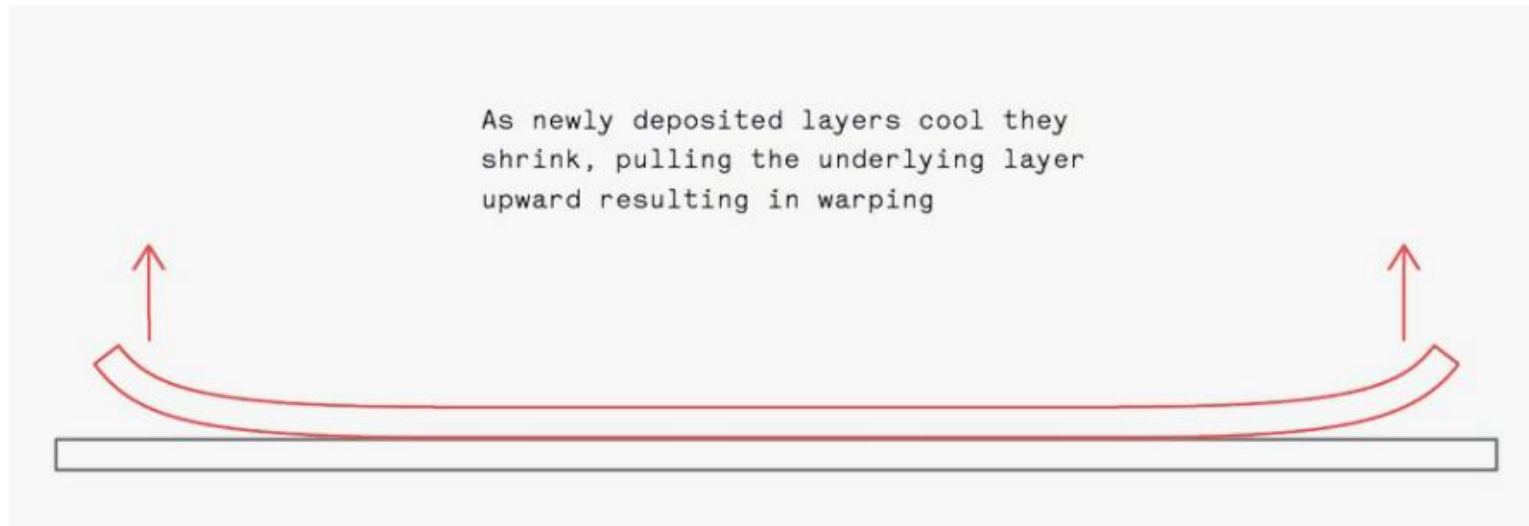
When using FDM, account must be taken of the available **construction volume**. Desktop printers offer an average of **200 x 200 x 200 mm** construction chamber. Larger **industrial machines** can also have **1000 x 1000 x 1000 mm** construction chambers. For very large parts, usually the best solution is to **assemble the parts** after printing.



>>> Properties of material extrusion

Deforming

The deformation of FDM components occurs due to **uneven cooling**. As some of the printed parts cool at different paces, they contract and **shrink**. This contracts the surrounding areas that creates **internal tension** that can lead to **warping** or distortion. The **heated tray and the good adhesion surface** plays an important role in binding the FDM component, reducing the likelihood of distortion.

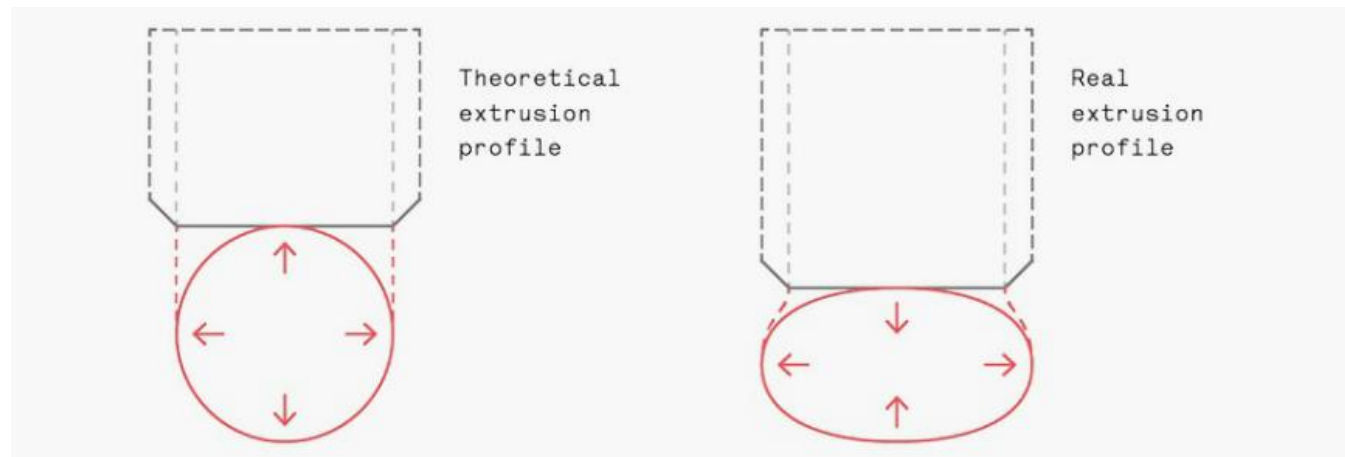


Properties of material extrusion

Layer adhesion

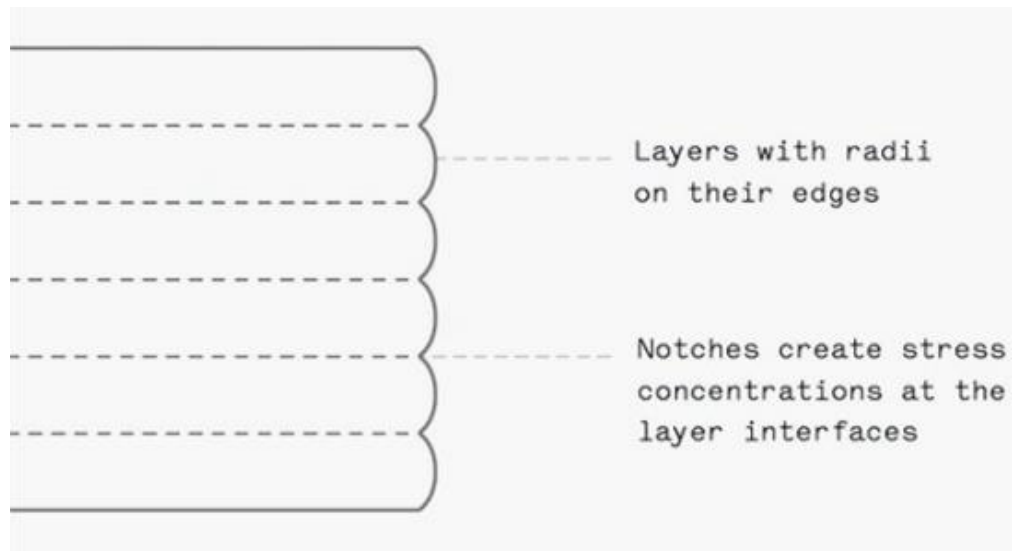
Adhesion or connection of the layers is an **important part** of the FDM printing process. As the filament is extruded, it **must be tied** and solidified with the **previously printed layers**, thus creating the solid cohesive part.

To achieve this, filament is **compressed with the previous layers**. The hot extruded material re-heats and **melts** the material of previously **printed layers**. **Downlink strength** and **partial re-melting** allow the new layer to connect the previously printed layers. This also means that FDM Filament is actually **placed in an oval form** instead of circle.



>>> Properties of material extrusion

As the layers are printed in **oval form**, the **bonds between the layers** actually form **small valleys**. This results in a **tension concentration** where there may be a crack due to the load, which leads to inherent **anisotropic** behavior and **rougher surface finish** of FDM-printed parts (different directions have different properties) and **layered appearance**.





Properties of material extrusion

Support structures

FDM components **may need support** for successful printing. Supports for all **overhanging forms** that are more **flatter than 45 degrees** compared to the base plane.

New layers **can not be printed into the air**, a solid stand is needed to build it. If there is no layer below it to print, we **add support** structures. This **allows** printing of forms that would otherwise not be possible. The support material is a **small volume, lattice structure** that **must be removed** after printing.



Overhangs less than 45° degrees,
supports are needed



Overhangs more than 45° degrees,
supports are not needed



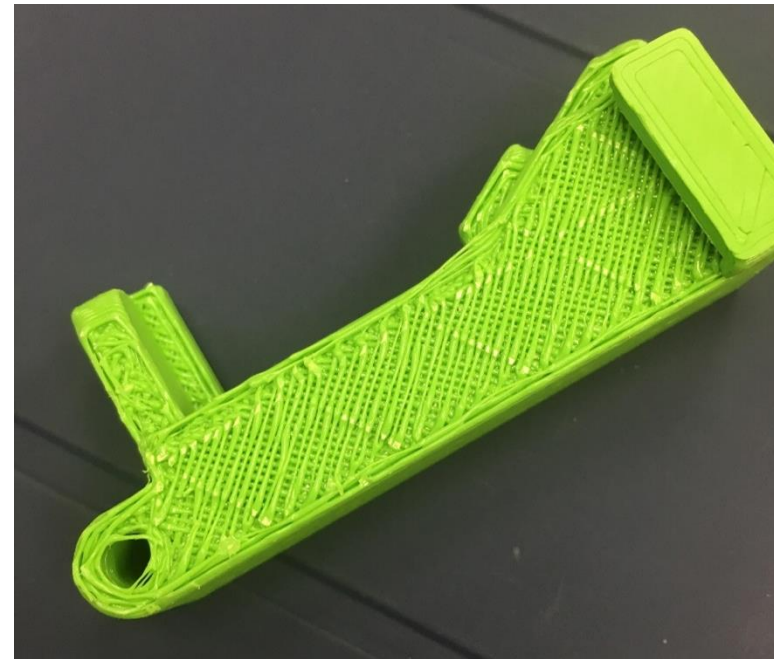


Properties of material extrusion

Although **lower than 45 degrees** overhangs **can be printed** (due to stickiness of the molten filaments), the **tilted surface quality will suffer**. If we need fast printing for fit and **form control** of the borders the overhang could be extended to less than 45 degrees angles. It is **recommended to comply with the 45 degree limit** for smooth and accurate prints.

The disadvantage of the support is that it has an **adverse effect** on the **surface** with which it is in contact because it may result in a coarse, damaged surface.

Post-processing is usually required when you want a **smooth surface**. This should be taken into account when the component is oriented on the **building plate**. Usually, it is best to **minimize** the **contact** of the supporting structures with the cosmetic **surfaces** (which is clearly visible, what you want to be beautiful) .





Properties of material extrusion

Soluble supports

Many new FDM printers use **dual extrusion** (two printheads) and are able to print parts made of multiple materials. For these printers, the **support structures** can be printed in **soluble material** (usually PVA or HIPS).

Since the support is **dissolved in water** or solvent and is not mechanically removed, the side of the support contact with the support side has an excellent surface. The use of soluble support generally **increases the cost of manufacturing** due to the soluble **fiber price** and **increase in print time**.



➤➤➤ Properties of material extrusion

Filling

FDM components are usually **not solid**. In order to reduce material savings and reducing the construction time, the interior of the components is printed with a **low density structure** called **infill**. The percentage of infill is a parameter that can be **varied according to the use of a component**. For great strength, the parts can be printed with 80% filling. If a model is used only for form and fit testing, the filling percent can be reduced to 10%, enabling the component to be prepared by **faster and lower costs**. The **20%** of FDM printing is a frequent infill percentage.

The **geometry** of the infill also **affects** the **capabilities** of FDM parts. The usual fill geometries include the **triangle, rectangle** and **honeycomb**. Some slicing programs allow fill density and geometry to **change during printing**.



Properties of material extrusion

Accuracy

Larger parts or thinner details are exposed to **high temperature fluctuations** due to the risk of **warping**. This can be solved by printing "**rafts**" (first a base layer is added to the tray and then the printed part itself) and the use of **heated plates**, the breaking or **rounding** of the pointed **corners**.

Parameters	Description
Tolerance	$\pm 0.5\%$ (± 0.5 mm lower limit). In Z direction, the result of printing is typically more accurate.
Shrinking/deforming	The high fusing temperature requiring thermoplastic polymers are risky. The shrinkage property is difficult to predict and depends heavily on the design.
Support requirement	Indispensable to printing accurate objects for surfaces lower than 45 degrees and bridges longer than 20 mm.





Properties of material extrusion

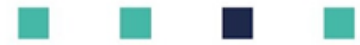
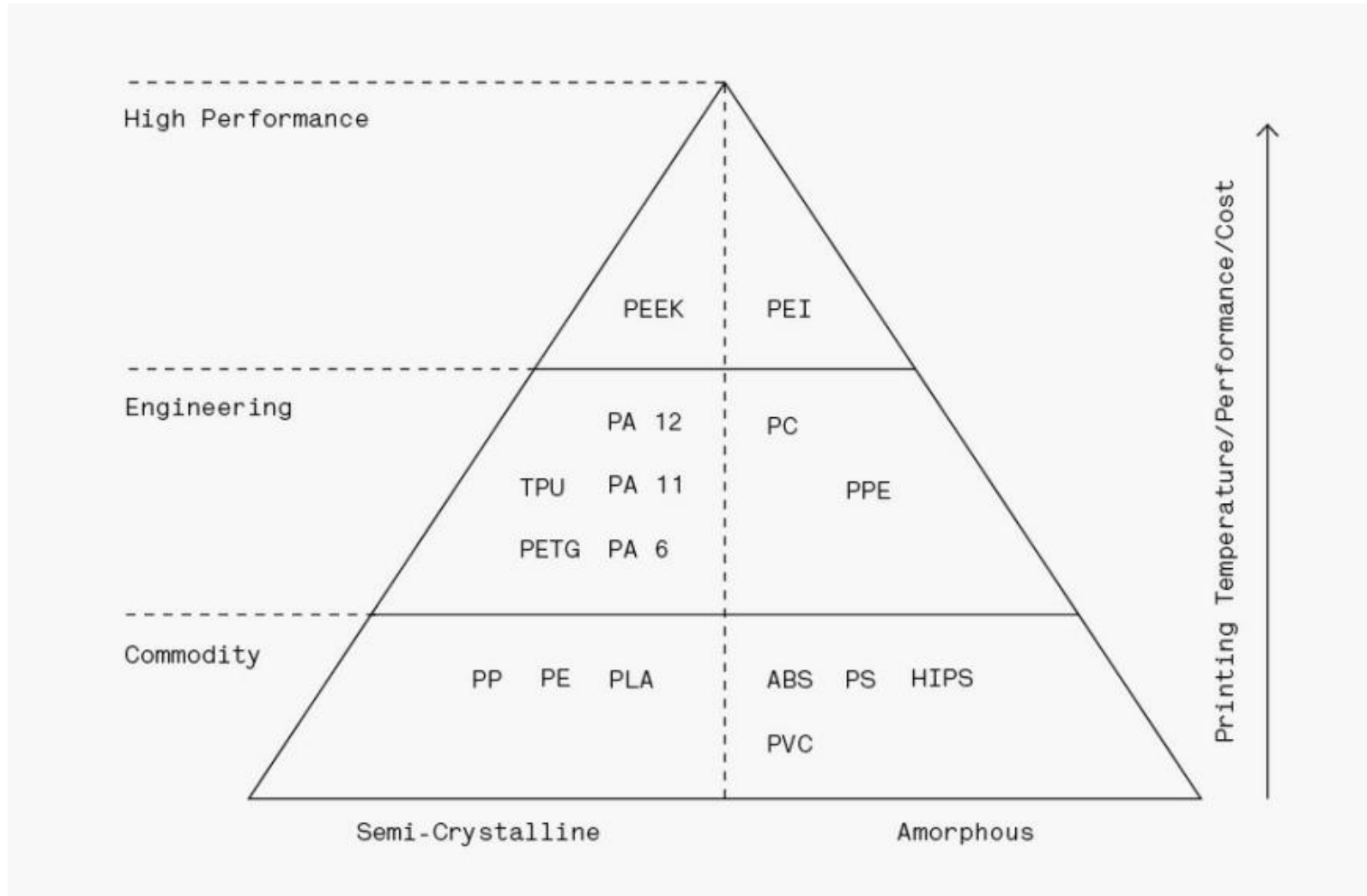
Materials

Filaments used in FDM printing are typically made of fibers with a **diameter of 1.75 mm or 3 mm** which are wrapped in a spindle. FDM filaments are the **cheapest materials** used in 3D printing eg. PLA (17-34 Euros / kg), although the price of high performance filaments, such as PEEK, can spread up to 420 Euros / kg. One feature of FDM printing is that the filaments are available in **plenty of colors**.

The general rule of thermoplastic polymers is that the **better the technical properties**, the **higher the temperature** is needed to be heated to the plastic state and therefore it is **harder to print** the material. Higher printing temperature **increases the likelihood of warping** or distorting during the printing process as the parts **cool faster**, generating more intensive **internal tensions**.



Properties of material extrusion





Industrial and desktop FDM printers

FDM technology is also used for cheap table 3D printers and high-end industrial machines. Most **cheap desktop** FDM printers are **technically similar** to high-end **industrial counterparts**, but their **abilities differ** significantly.

The main difference between industrial and desktop FDM is the **choice of available materials**. Industrial machines can produce parts from the same **standard thermoplastic polymers** such as desktop printers, but they can **precisely print** the more complex, technical thermoplastic polymer components that can **otherwise be difficult** to print.

Due to precisely **regulated** manufacturing **environments**, industrial machines generally produce **greater precision** components, better repeatability. The manufacturing volume of industrial machines is also **more spacious**, so larger or more than one component can be manufactured. Therefore, **industrial** machines are used for **small and medium manufacturing** volumes, while **desktop** printers are more practical for **prototype development**.





Industrial and desktop FDM printers



Desktop FDM printer (Ultimaker 3)



Industrial FDM printer (Stratasys Fortus 400mc)



Application of material extrusion

Casting patterns

The **low cost** of FDM materials and the **quality of geometry** produced by the process can be a good solution for the production of casting patterns. Since the filling structure printed inside the FDM components is **not solid**, it also allows to made of **less material** and **making burnout easier** during the casting process.



Printed FDM patterns (left side) and the final metal investment cast part (right side)

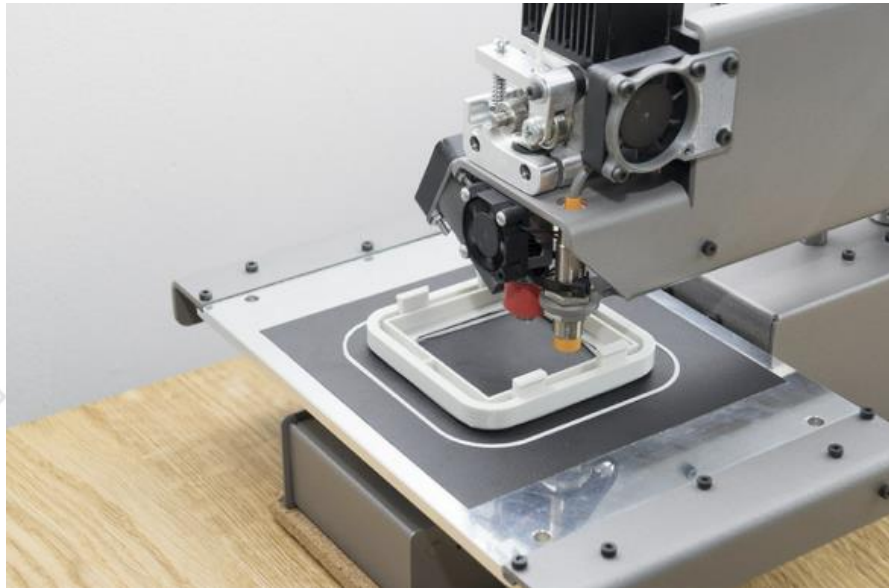




Application of material extrusion

Electronics housings

Electronic housings or enclosures are one of the **most popular applications** for FFF printing. FFF allows a designer to create a **prototype** or final design in a **matter of hours** and is much **cheaper** compared to traditional manufacturing methods. 3D printed enclosures offer an effective method of confirming design geometry and several of the materials that can be used for printing enclosures are suitable for end use applications.





Additional material Extrusion technologies

Continuous Filament Fabrication - Markforged

In essence, Markforged (CFF) technology is the **same as FDM technology**. What differentiates CFF is the addition of a **second print head**, which reinforces the printed nylon by embedding a **continuous strand of carbon fiber**, kevlar or fiberglass **within the layers**.

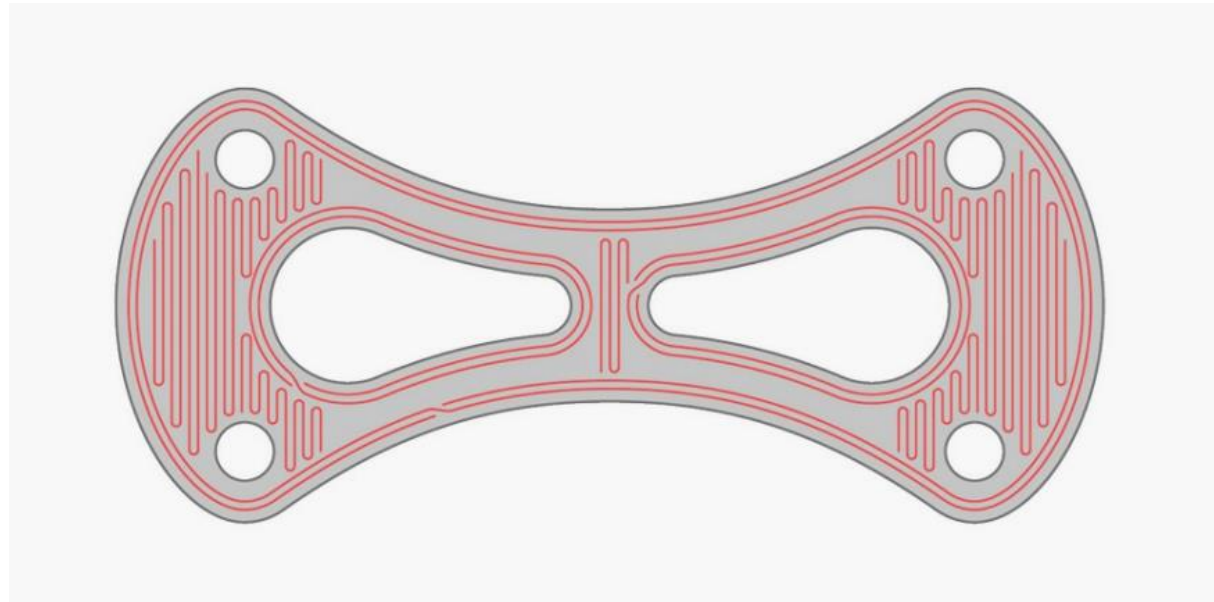




Additional material Extrusion technologies

Continuous Filament Fabrication – Markforged

These long, **continuous strands carry the load** down the entire object, resulting in strong, functional parts leveraging the properties of composite materials. Engineers can precisely analyze and **dictate the density and patterns** in which the chosen fiber is embedded in the printed part.



Using the Markforged Eiger software, users can determine how the carbon fiber (red) and nylon (grey) will be laid out on each of the layers within the print.





Additional material Extrusion technologies



Nylon brake lever prototypes 3D printed on the Markforged printer with different types of fiber reinforcement. From top to bottom: nylon without reinforcement, fiberglass reinforced nylon, kevlar reinforced nylon, carbon fiber reinforced nylon and a carbon fiber reinforced Onyx print.

[CFF video](#)





Additional material Extrusion technologies

Metal FDM – Markforged Metal X

The Metal X machine from Markforged prints a **plastic filament impregnated with metal powder**. After printing, the part is **sintered in a furnace**, causing the **plastic to burn off** and the **metal powder to bond together**, resulting in a robust metal part. This process is referred to as Atomic Diffusion Additive Manufacturing (**ADAM**) and is similar to the way Binder Jetting produces functional metal parts.

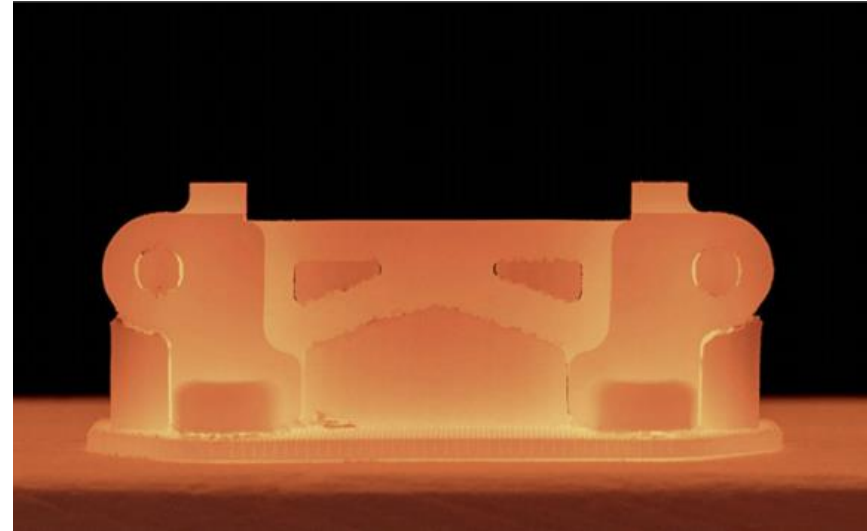
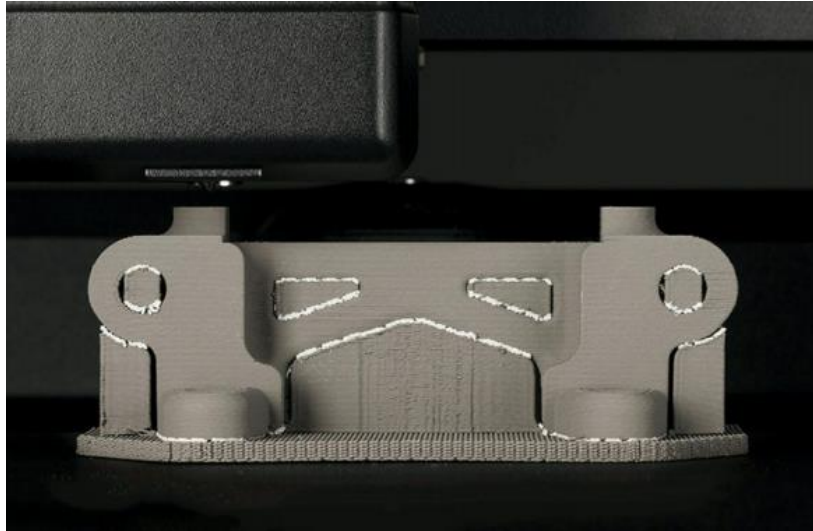


[Metal X video](#)





Additional material Extrusion technologies

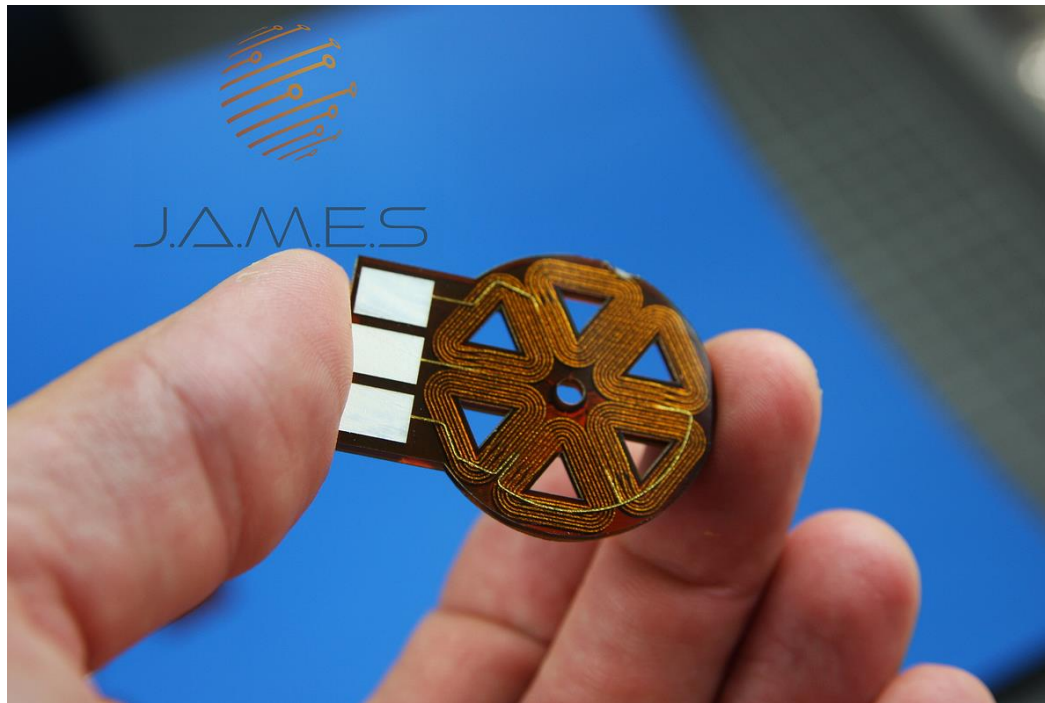




Additional material Extrusion technologies

Integrated circuit printing - Dragonfly IV

The DragonFly IV is an industrial electronics 3D printer manufactured by Nano Dimension. The Nano Dimension DragonFly IV uses material jet 3D printing technology. This PCB 3D printer offers a build volume of 160 x 160 x 3 mm.



[Dragonfly IV videó](#)

[Dragonfly IV weboldal](#)

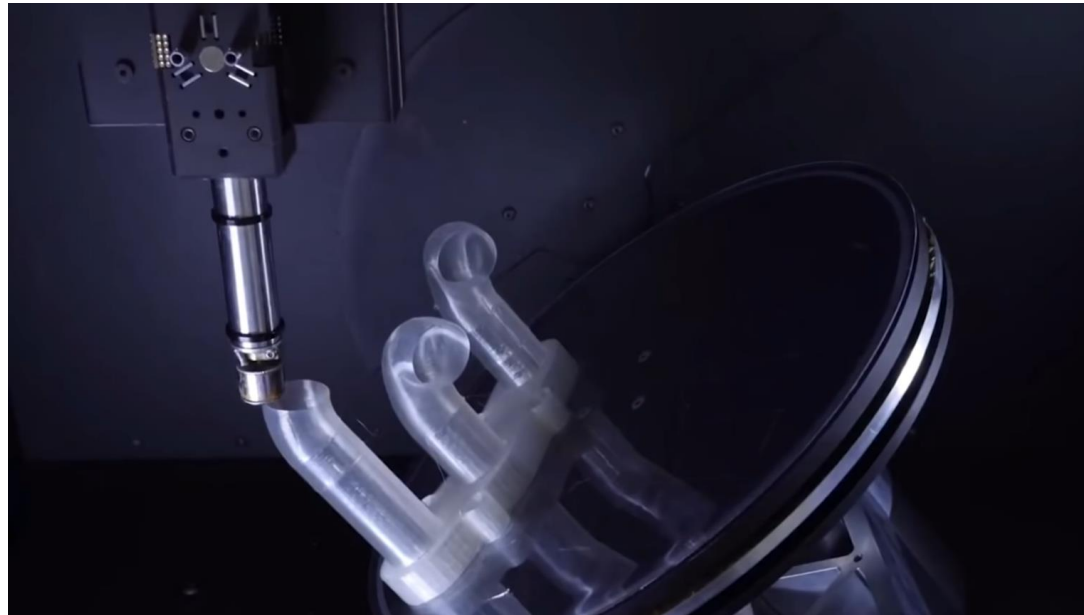




Additional material Extrusion technologies

5-axis printing - VSHAPER

The indexed 5-axis print allows the model structure to be reinforced in any direction within an object by transferring the plane on which the subsequent toolpaths are applied to another previously printed surface.



[VSHAPER videó](#)

[VSHAPER weboldal](#)





Sources

- 3D printing processes – Wikipedia
- The 3D Printing Handbook – Ben Redwood, Filemon Schöffner, Brian Garret
- 3D printing filament comparison – Three dot zero studios

