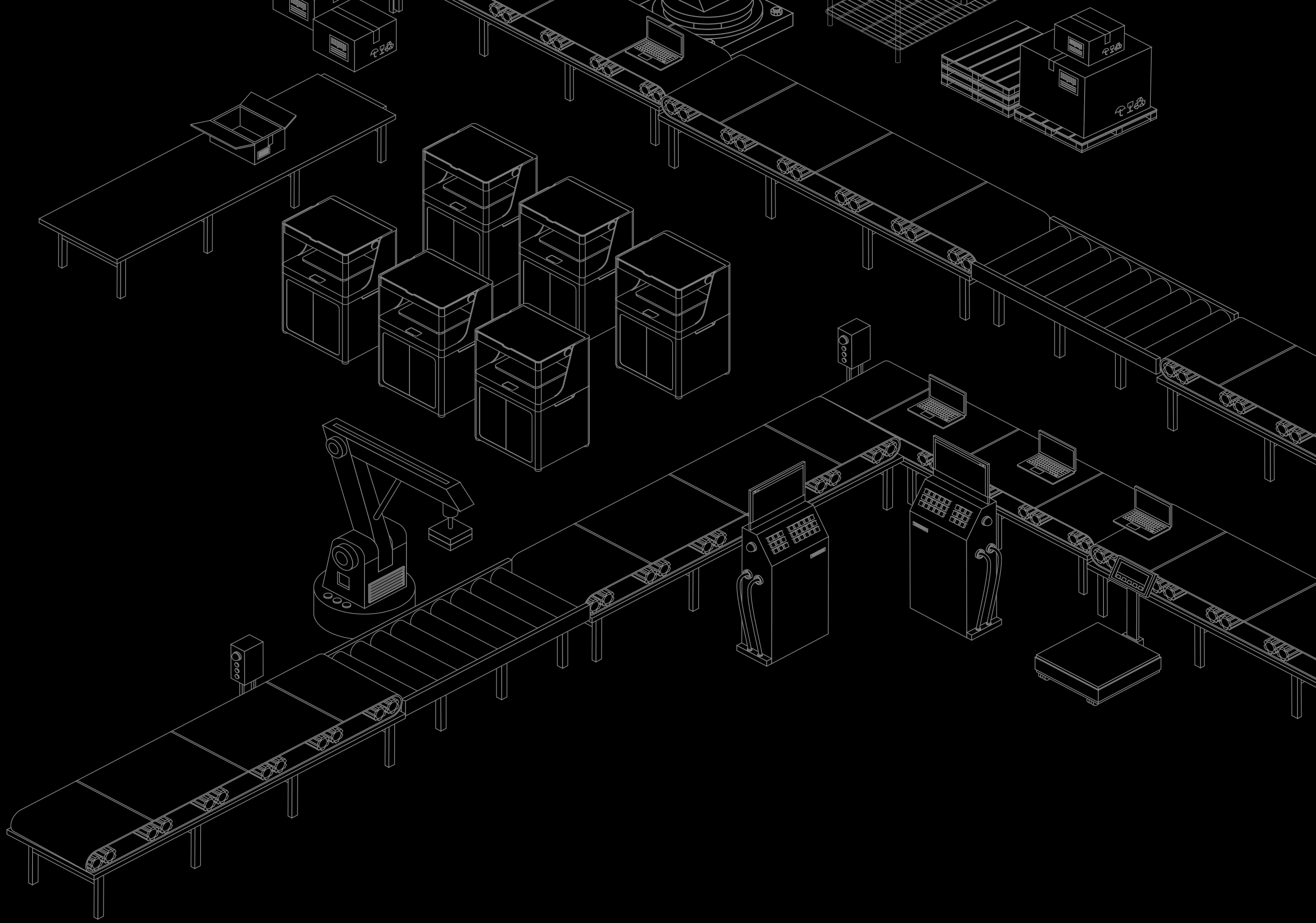


MARKFORGED WHITE PAPER

3D PRINTING BUYERS GUIDE

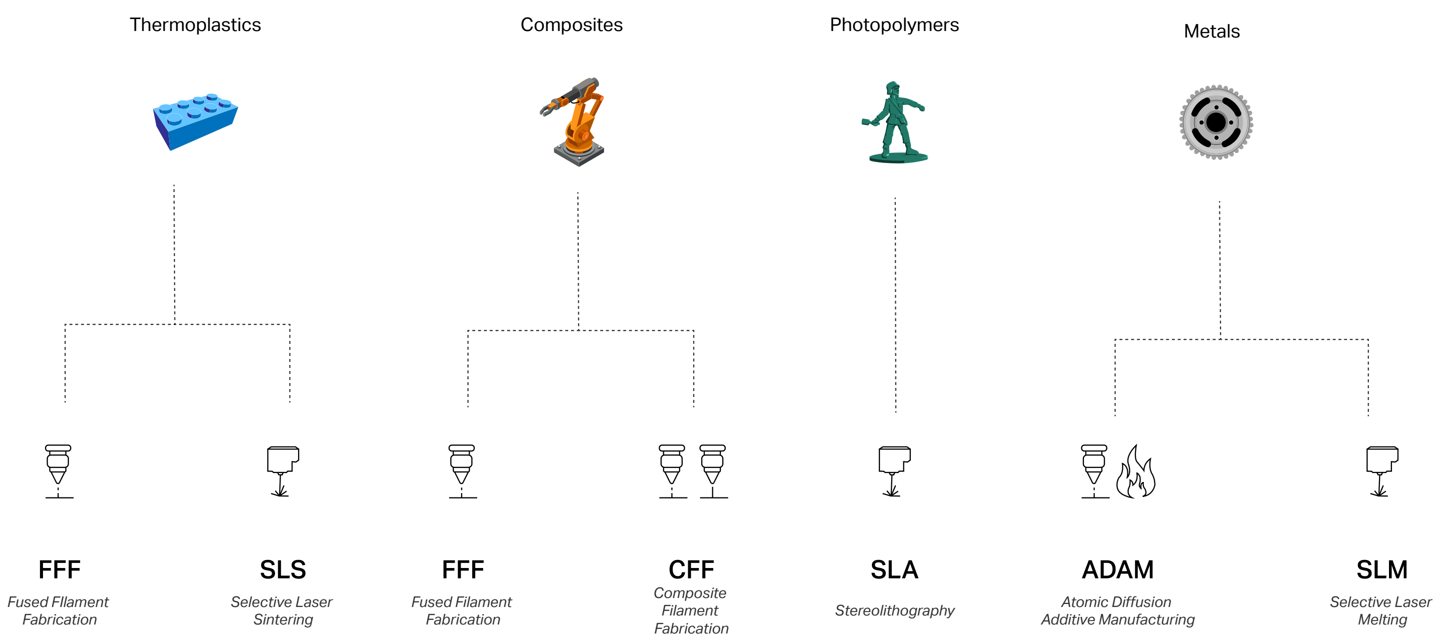
3D printing has become a powerful force in today's manufacturing industry. The process can take many forms, as the industry offers a variety of materials, methods, and machines. Many businesses struggle to find additive manufacturing solutions that suit their needs and provide an efficient return on investment (ROI). Selecting the right tool to target manufacturing roadblocks is vital to maximizing your manufacturing line productivity at low cost.

SUMMARY

ADDITIVE MANUFACTURING

Additive manufacturing solutions vary vastly in the industries they most effectively service. Certain materials and methods are tailored toward specific applications. When the correct solutions are paired with defined roadblocks, customers see high returns in both time and cost. By establishing manufacturing objectives and understanding methods common to additive manufacturing, you can pinpoint a cost-effective solution that will streamline your workflow.

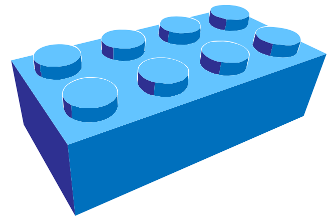
ADDITIVE MANUFACTURING TECHNOLOGIES



MATERIAL

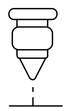
THERMOPLASTICS

Thermoplastics are some of the most common materials in additive manufacturing. Thermoplastic 3D printing processes involve heating a plastic material until it is semi-formable to create a shape. Common thermoplastics are often tough, deforming rather than fracturing under stress, but they have a relatively low melting point along with low chemical and abrasion resistance.



FFF

Fused Filament Fabrication



Fused Filament Fabrication (FFF) is the most widespread 3D printing technology. In this process, a thermoplastic material is heated and extruded through a nozzle. As the nozzle of the printer moves it deposits a cross-section of the model being printed. This process is repeated layer by layer until the model is completed. Printed models can be hollow or low density with designated internal fill percentages. Thermoplastic fused filament fabrication is most commonly used with low-fidelity prototypes and models.

PROS

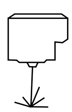
simple
affordable & accessible technology
lightweight

CONS

limited materials
weak parts
anisotropic
prone to wear
poor surface finish

SLS

Selective Laser Sintering



The Selective Laser Sintering (SLS) 3D printing process utilizes a laser to melt and bind powdered thermoplastics into a given shape. The parts are printed in a chamber of plastic powder. Each layer, a roller sweeps new powder over the chamber, a laser selectively melts a cross-section of the part within the powder, and the chamber recesses to make room for the next powder layer.

PROS

high detail
full density parts
isotropic properties
wide range of materials

CONS

costly
respiratory protection required

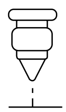
MATERIAL

COMPOSITES

Traditionally, composite materials are highly valuable because of their material properties. Well known and heavily utilized composites like carbon fiber deliver high strength to weight ratios for automotive and aerospace industries. With the recent innovation of 3D printing composite materials, parts can be made strong enough for use in engineering applications where the material properties of more common printing methods would not be sufficient. In 3D printing, composite materials can effectively replace traditionally machined aluminum components because they combine the strength and stiffness of metal with the ease of additive manufacturing.

FFF

Fused Filament Fabrication



Some composite materials can be 3D printed using FFF methods. These materials are composed of chopped fibers (commonly carbon fiber) mixed with traditional thermoplastics like nylon and PLS. While the FFF process remains unchanged, the chopped fibers increase the stiffness, strength, and surface finish of the model, and greatly improve dimensional stability and precision.

PROS

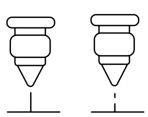
improved dimensional stability
heat deflection
part precision
part strength

CONS

limited materials
weak parts
anisotropic
prone to wear

CFF

Continuous Filament Fabrication



The Continuous Filament Fabrication (CFF) 3D printing process is a cost effective solution for replacing metal parts with 3D printed parts. CFF 3D printers lay continuous strands of composite fibers (usually carbon fiber, fiberglass, or Kevlar) within or alongside FFF extruded thermoplastics during the printing process. The reinforcing fibers form the backbone of the printed part to achieve exceptional stiffness and strength.

PROS

stronger than 6061 aluminum
20x stronger than thermoplastic FFF

CONS

lower surface hardness and corrosion resistance than ADAM

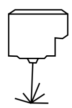
MATERIAL

PHOTOPOLYMERS

Photopolymer materials are liquid polymers that change structure when exposed to a light source. When catalyzed with UV radiation, these liquid resins become solid. Unlike thermoplastics, photopolymers cannot be melted as the polymerization process is a molecular change. Due to the specific properties that enable photopolymerization, resins are often brittle and not as long lasting as thermoplastics because they degrade over time from continued UV exposure.

SLA

Stereolithography



Stereolithography (SLA) printing technologies make use of photopolymers by selectively curing photopolymers with a UV laser. A laser selectively cures the resin to form a hardened layer, and repeats the process to build up the model layer by layer. Because of the chemical bonding process induced by photopolymerization, printed parts are fully dense and isotropic. SLA 3D printers often have a relatively small build volume but can achieve exceptional detail and surface finish with precise control of the laser beam.

PROS

Isotropic

highly detailed

smooth surface finish

CONS

small build volume

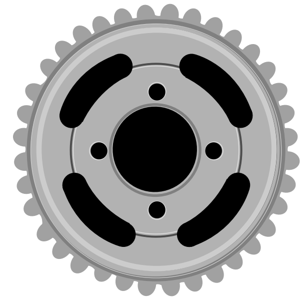
brittle parts

chemical protection necessary

MATERIAL

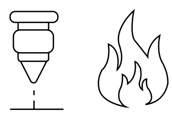
METAL

3D printing metal has been a longstanding goal in additive manufacturing, but has often been limited by cost, complexity, and material constraints until recently. Metals cannot be extruded as easily as thermoplastics and require high heat and power to achieve a formable state. In order to implement metal additive manufacturing, most solutions start with the metal in powder form and use various heating techniques to fuse the powders together. Many metal printing methods include post processing steps to fully strengthen or finish the printed parts.



ADAM

Atomic Diffusion Additive Manufacturing



Atomic Diffused Additive Manufacturing (ADAM) is a unique and cost effective metal 3D printing process that combines concepts from 3D printing and Metal Injection Molding. The metal powder common to SLM methods is encased in a plastic binder, which gets deposited layer by layer on a print platform by an extruder, very similar to FFF processes. After printing the part is washed and sintered in an oven, melting away the binder and allowing the metal powders to fuse and form an isotropic metal part. The ADAM process can be applied at an industry level to manufacture metal tooling like injection molding and can produce complex metal parts cost effectively.

PROS

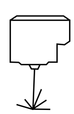
cost effective
variety of materials
similar to FFF

CONS

longer lead time to strong part than CFF

SLM

Selective Laser Melting



The process of Selective Laser Melting (SLM) involves melting fine metal powders in an inert gas chamber to build up a metal part. Layers of metal powder are distributed and then selectively melted with a high power laser to fuse the metal powders together. Like SLS, this is a layer by layer process, but parts can easily deform or warp due to high heat concentrations within the chamber. As a result, the SLM process has some geometry limitations but can be used for functional metal parts that would be too costly or impossible to machine like medical implants and weight-optimized parts. This process also requires multiple post processing operations to remove supports and clean off the part, and specific facility requirements are necessary for handling loose powder.

PROS

variety of metals
intricate detail level
metal-strength parts

CONS

part failure due to heat buildup
very costly
many post processing steps
many facilites requirements necessary
long lead time to finished part

MARKFORGED

MANUFACTURING REINVENTED

At Markforged, we are on a mission to unlock the next 10x innovation in design and manufacturing. We build an Industrial 3D Printing Platform to liberate designers and engineers from decades-old, slow processes. NASA, Google, Ford, Amazon, General Electric and thousands of companies in 50 countries use Markforged to print same-day prototypes and produce stronger end-use parts than they did before. With Markforged, they're able to ship 50x faster, spend 20x less, and build 20x stronger products.

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