Markforged

Design Guide for 3D Printing with Composites

Markforged

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Forces key

At several points in this guide we discuss different loading conditions with respect to print orientation. Due to the anisotropic nature of 3D printed parts, properties about or along the Z axis of printing — normal to the print bed — are different than those of the X and Y axes — parallel to the print bed. Properties and behaviors in this guide are framed in the context of the Z axis or the XY plane.

Important terms

Imporant terms from Eiger, the Markforged 3D printing software, will be highlighted in **BOLD CAPITAL LETTERS.**

Quick Reference Sheet

These guides serve as recommendations and may not reflect all implementations, as 3D printing is a geometry-dependent process. Unless otherwise specified, data is based on parts printed on Markforged composite printers at 100 micron layer height in Onyx with default print settings.
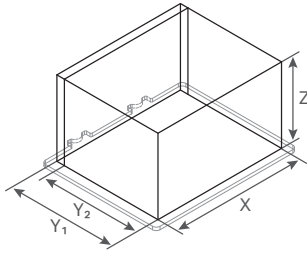
Plastic
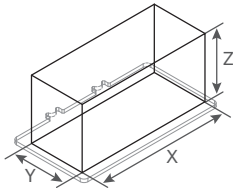
Maximum part size

Desktop Series
X: 320 mm (12.60")
Y: 132 mm (5.20")
Z: 154 mm (6.06")

Industrial Series
X: 330mm (13.00")
Y_1: 270 mm (10.63") Y_2: 250 mm (9.84") with fiber
Z: 200 mm (7.87")

These build volumes reference the maximum bounding box your part must fit in to print on either a Desktop or Industrial Series Markforged composite printer. Industrial Series printers have a deeper print area when printing with only plastic.

Please consider that auto-generated support material may increase your part's dimensions on the print bed by up to 1.5mm in any direction; for more information, see the *What to Consider When Printing* section below.
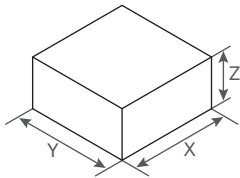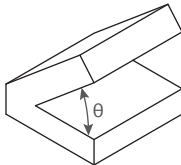

Minimum part dimensions

X: 1.6 mm (0.063")
Y: 1.6 mm (0.063")
Z: 0.8 mm (0.031")

Minimum part size is limited to the extrusion width and height of each bead. The dimensions are derived from the minimum number of roof layers, floor layers, and shells needed to print a part successfully.

Minimum unsupported overhang angle

θ: 40°

This is the minimum angle to the horizontal at which a feature of a part can print without needing supports to hold it up. Eiger will generate supports for angles below 45°, but may not be needed in all cases.
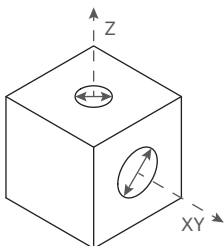
Minimum hole diameter

XY: 1.5 mm (0.059")
Z: 1.0 mm (0.039")

Holes with too small a diameter may close off during printing or print inaccurately. Horizontal surface holes (Z) print more precisely than vertical surface holes (XY).

Quick Reference Sheet

Markforged

Minimum post diameter

XY: 1.6 mm (0.063")
Z: 2.0 mm (0.079")

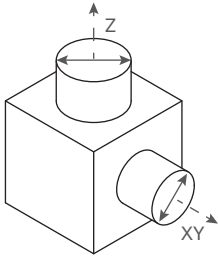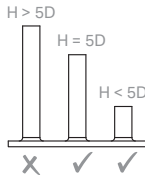Posts with too small a diameter may not print precisely. Consider adding dowels or pins to your part for strong vertical posts to avoid shear along layer lines.

H > 5D
H = 5D
H < 5D

Important note: Avoid printing posts with heights (H) more than five times their diameter (D). Tall posts are more susceptible to shear on layer lines. If you do print posts, fillet interfacing edges to reduce stress concentrations.
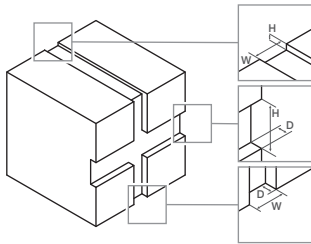
Minimum engraved feature size

Z Layer features
H: 0.10 mm (0.004")
W: 0.50 mm (0.020")

Horizontal XY features
D: 0.20 mm (0.008")
H: 0.80 mm (0.031")

Vertical XY features
D: 0.20 mm (0.008")
W: 0.50 mm (0.020")

An engraved feature is one that is recessed below the surface of the model. Common examples include lettering and texture. Engraved features may blend into the rest of the model if they are too small.
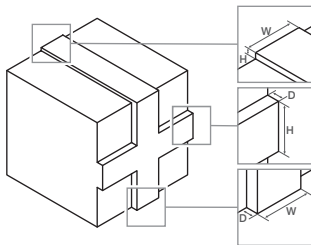
Minimum embossed feature size

Z Layer features
H: 0.10 mm (0.004")
W: 0.80 mm (0.031")

Horizontal XY features
D: 0.20 mm (0.008")
H: 0.80 mm (0.031")

Vertical XY features
D: 0.20 mm (0.008")
W: 0.80 mm (0.031")

An embossed feature is one that is raised above the surface of the model. Common examples include lettering and texture. Embossed features may blend into the rest of the model if they are too small.

1.6 mm
(0.063")
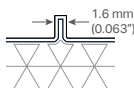
Important note: To prevent gaps on features less than than 2 mm (0.078") wide, design embosses to be even multiples of 0.4 mm (0.016"), the width of a single extrusion of plastic.

Quick Reference Sheet

Fiber

Minimum fiber reinforcement feature width

Open feature
W: 3.6 mm (0.15")

Looped feature
W: 2.8 mm (0.11")

Thin reinforced features must allow the fiber to double back and meet the endpoint of the fiber with its start. While the minimum width (W_{open}) of an "open" feature on a part must fit two fiber strands, the minimum reinforcement width (W_{looped}) can be thinner if the segment in question allows the fiber to form a loop.

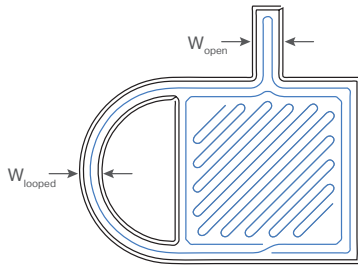### Minimum fiber reinforcement part height

Fiberglass, HSHT, Kevlar®
**H: 0.9 mm (0.035")**

Carbon Fiber
H: 1.125 mm (0.04")

Four roof and four floor layers of plastic are needed above and below Fiber Groups, meaning the minimum reinforceable height (H) is nine layers thick, leaving one layer for fiber. This value changes with fiber selection since some fibers print at different layer heights.

### Minimum fiber length

L: 45 mm (1.77")

The smallest area you can reinforce with fiber is limited to the smallest strand of fiber that can be laid down and cut. This minimum strand length (L) can materialize in a few ways but must also meet the reinforcement width criteria.
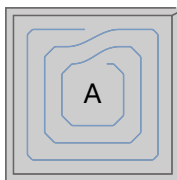
Smallest reinforced area

Area: 90 mm² (0.14 in²)

Independent of part shape, the smallest reinforceable area is about 90 mm (but may vary based on specific geometry). The part must also meet the minimum width requirements listed above.
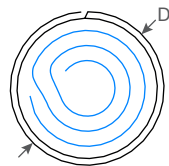
Smallest reinforced post

Post Diameter: 9.6 mm (0.38")

It is possible to reinforce vertical posts down to 9.6 mm (0.38") in diameter. However, vertical printed posts may shear along layer lines, so consider integrating dowels, rods, or pins into your part for strong posts.

Smallest reinforced holes
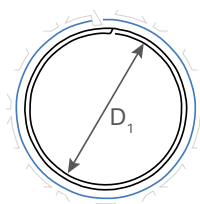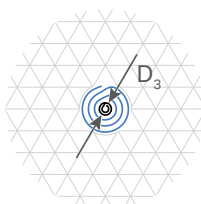
Three rings
D_3: 0.5 mm (0.020")

Two rings
D_2: 3.85 mm (0.152")

One ring
D_1: 12.16 mm (0.479")

Sometimes holes are too small to reinforce with a given number of concentric fiber rings because of the minimum fiber length. In these cases, you can simply increase the number of **CONCENTRIC FIBER RINGS**. Here are the minimum hole sizes for 1-3 rings of fiber.

Identifying 3D Printing Opportunities

3D printers vary widely in size, material, and method — simply put, they are just tools to help you create specific parts. Just as you wouldn't use a screwdriver on a nail, a 3D printer is well-suited for certain types of parts and ineffective for others. The key to determining whether to 3D print a part stems from its material properties and return on investment (ROI).

Calculate ROI

Use ROI calculations to justify which parts or subassemblies will benefit from 3D printing. Upload your parts to Markforged's Eiger software to get the material cost and print time, and compare this to estimates from other manufacturing platforms. This should give you a sense for the time and cost savings involved in creating your part.
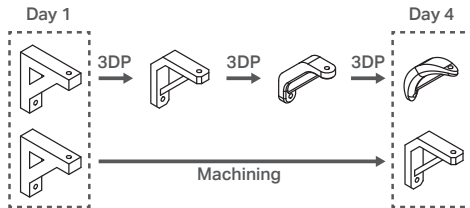
Time analysis

3D printing allows for rapid iteration so you can test out many different designs early and often to refine your models. Continuous fiber reinforcement facilitates strong parts for works-like prototypes and end-use that you can improve print-by-print and implement in a matter of days. Look for opportunities to cut down on lengthy lead times with additive manufacturing.
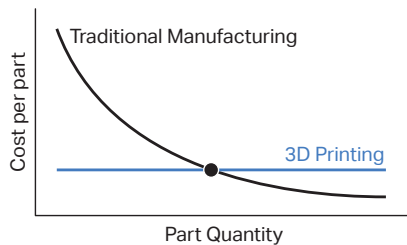
Cost considerations

Turn to 3D printing when the costs of traditional manufacturing are prohibitively expensive for your needs. 3D printing is often appropriate for low- to mid-volume applications, but for a given part there is always an inflection point at which other manufacturing methods become more cost-effective. Compare cost-per-quantity values to discover this tipping point.

Determine material needs and behaviors

Consider the material requirements of your part.

- How strong or stiff does it need to be?
- What environment will your part be in?
- How many cycles does it need to last?
- How much can it weigh?

Use these considerations to select a material that suits the part.

When should you print with continuous fiber?

Continuous Fiber Fabrication (CFF) serves as the backbone for strong 3D printed parts. Inlaid fibers within a printed plastic matrix form a composite part in which the properties of the fiber provide high stiffness, toughness, strength, or heat deflection.

Metal strength

The strength of a fiber reinforced part comes from the combined strength of the plastic and the continuous fiber strands woven throughout the part. This can make parts comparable to aluminum in strength and stiffness.

Durability

Reinforcing fibers can vastly increase the lifetime of a part. Fibers strengthen the part far beyond traditional plastics, meaning a reinforced part can hold up much better over an extended period of time than a standard plastic part.
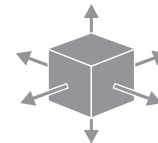
Optimized properties

Continuous Fiber Fabrication is unique in that you can selectively reinforce a part for its use-case. Tailor a part's strength profile exactly for its application by adding continuous fibers where strength is needed most.

What to Consider When Printing

As you design your part, consider how it can be optimized for the layer-by-layer printing process. Below are six considerations to keep in mind when designing your parts:
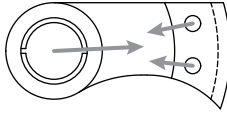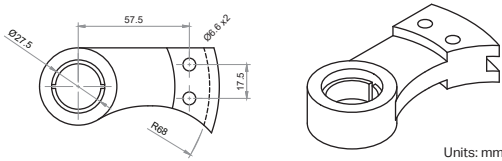
1. Determine loading conditions

Composite 3D printed parts are stronger on planes parallel to the print bed, especially if you are reinforcing with continuous fiber. Analyze how your part will be loaded and design the part such that the largest forces traverse the XY plane. Some parts may need to be split into multiple printed pieces to optimize for strength.

2. Identify critical dimensions

3D printers have higher precision in planes parallel to the build plate. What are your critical dimensions or features? Critical features print optimally when in plane with the print bed.

Units: mm
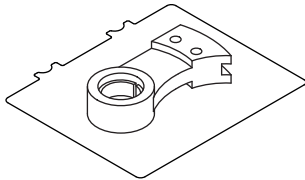
3. Maximize bed contact

Greater surface area on the print bed minimizes supports and improves bed adhesion. Which face of your part contacts the bed? Try to orient the part so that the largest face lies on the print bed, unless strength or geometry needs dictate otherwise.
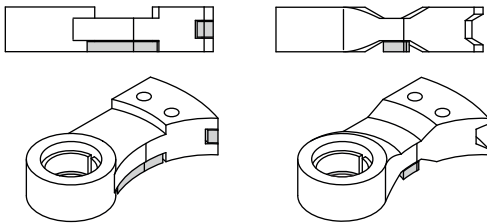
4. Reduce supports and improve overhangs

Fewer supports reduce printing and processing time. How can you design to minimize supports? Are the supports in your part accessible? Use angled overhangs to reduce supports and improve support removal.
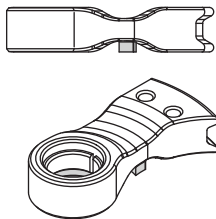
5. Fillet or chamfer edges

Adding fillets ensures smooth edge transitions and reduces stress concentrations at corners. Filleting edges normal to the print bed reduces the potential for warping, while chamfering edges flush with the build plate makes part removal easier and prevents edges from splaying on the first layer. Chamfers on interface edges like holes will help line up fits more easily.

What to Consider When Printing

6. Consider printer bandwidth

Consider when you use your printer and how to make efficient use of its bandwidth. Print longer jobs overnight and shorter jobs during the day. You can also create builds by printing multiple parts together that start and end during a workday. Here is a table of guidelines and four example days of prints to help you:

If print time is...	Then kick off at...
0 to 8 hr (+ X days)	Start of workday
8 to 16 hr (+ X days)	End of workday
16 to 24 hr (+ X days)	Middle of workday

Example 1: Ideal
One 8 hr print + One 16 hr print

Start of workday
9 am

End of w orkday
5 pm

8 hr

16 hr

100%
uptime
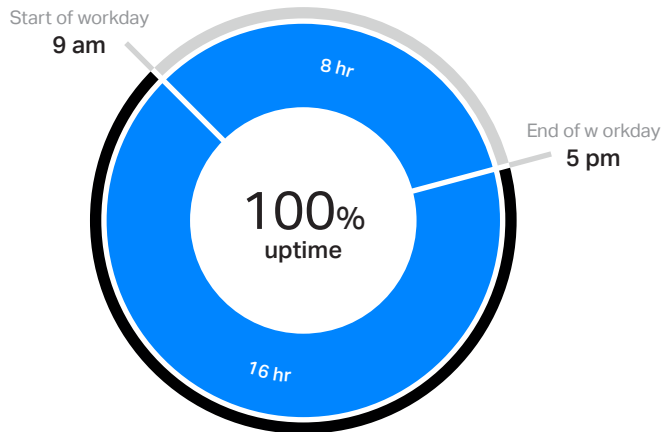
Example 2: Ideal
One 20 hr print + Four 1 hr prints

Start of workday
9 am

End of workday
5 pm

1 hr 1 hr 1 hr 1 hr

20 hr

100%
uptime
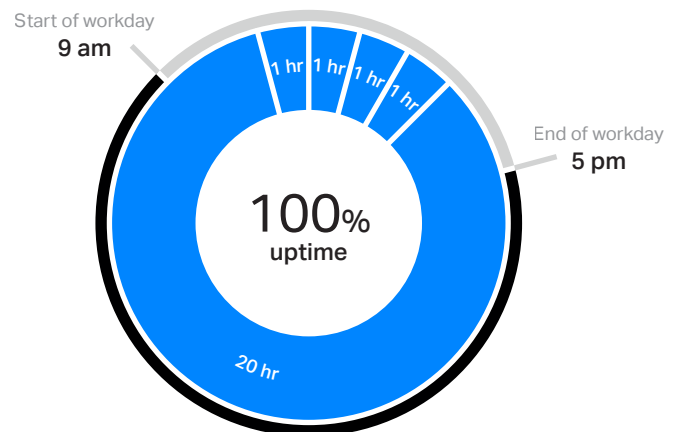
Example 3: Non-Optimal
One 13 hr print + One 2 hr print + 9 hr downtime

Start of workday
9 am

End of workday
5 pm

2 hr

13 hr

9 hr

63%
uptime
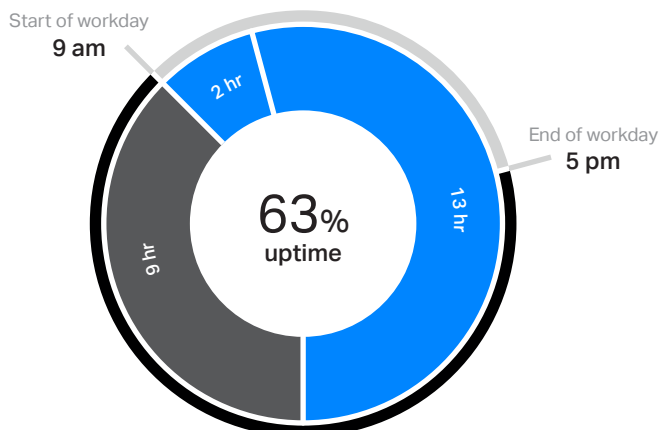
Example 4: Optimized
One 13 hr print + One 4 hr print + Two 2 hr prints + 3 hr downtime

Start of workday
9 am

End of workday
5 pm

2 hr   2 hr

4 hr

3 hr

13 hr

88%
uptime

	working hours		non-working hours		print in progress		printer downtime
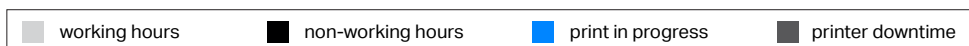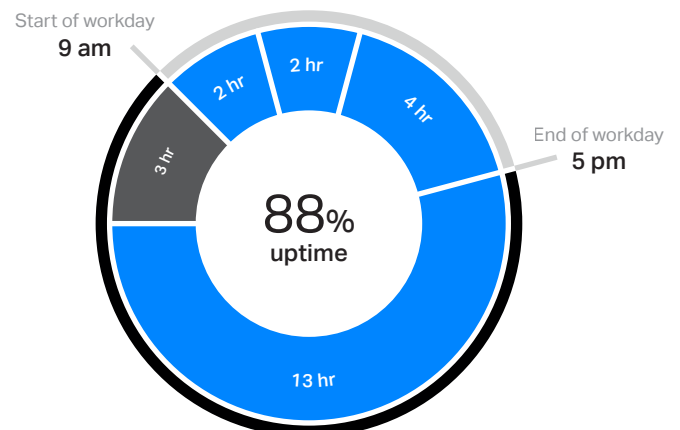
Strategic 3D Printing Design Practices

Think critically about which aspects of your design need to be 3D printed. Some features could be implemented more efficiently with other manufacturing methods. When appropriate, integrate other parts into your design to save on print time and cost or to improve important features. Below are a few examples of where simple hardware integrations can improve part success.
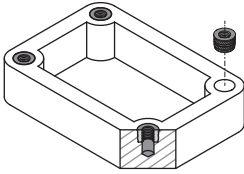
Threads and inserts

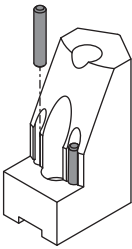Instead of printing or tapping threads into plastic, add a metal heat-set insert where you need threads. These inserts get pressed in with a soldering iron to reflow the plastic around the part for local isotropic strength. Inserts are stronger and last longer than printed or tapped plastic threads.

Wear surfaces

Dowel pins provide a hardened steel wear surface for areas of parts that interact with abrasive surfaces. In this example, robotic end effectors grip a threaded pipe coupling. The dowel pins prevent the threads from cutting into the printed plastic, increasing the lifetime of the grippers.
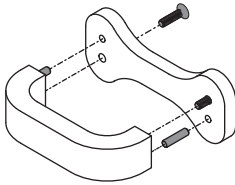
Alignment

Use pressed-in dowel pins or shoulder bolts to precisely align multiple components. Press-fit dowel pins are used to line up this handle with its baseplate, while screws secure it. Use dowel pins for alignment before glueing or bolting the components together to attach multiple printed parts precisely.
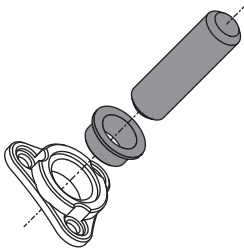
Concentricity

Bushings or sleeve bearings like the ones inserted into this bracket provide high cylindrical precision and smooth concentric clearance fits. Off-axis loads distribute to the printed part with the bushing's larger surface area. The bushing cavity can be reinforced with continuous strand composite fibers for higher torsional resistance.
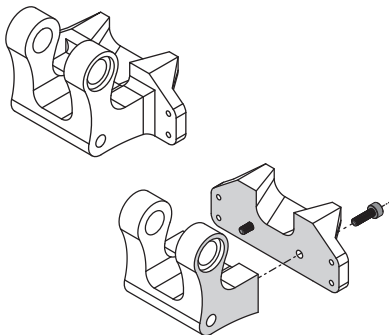
Splitting up parts

Sometimes it is more effective to split up a part than to print it as one piece. This part is split in two, with each piece printed from its highlighted face to prioritize the strength of each segment. Here are some reasons to consider splitting a part up:

- Parts with many iterations or customizations can be designed with a core base geometry and interchangeable modules

- Elements of parts that undergo increased wear or strain can be isolated into components that can be changed out regularly

- Designs requiring specific strength profiles across multiple axes can be printed in sub-components in different orientations and joined post-print

- Complex prints with critical features on multiple planes can be split into sections to reduce supports, decrease print time, and ensure print success

Strategic 3D Printing Design Practices

Use unit tests to validate geometries and save print time

In software development, a unit test is used to confirm that a small section of code works before its integration into a larger program. 3D printed unit tests work much the same way. A 3D printed unit test is a small test print that confirms feature success before committing to a long, costly print.

Unit tests can be designed to experiment with different clearances and select the fit most appropriate to your application. Isolate the critical segments of large parts and print multiple versions with slightly altered dimensions or configurations to test how they interface. Update your final CAD model with the specification you find works best, and print it with confidence in its success.

Tutorial: Designing a unit test

1. **Identify critical features** in your CAD model that either require tolerance verification or need to be tested to confirm they print as expected.

2. **Isolate features in question** as a part file or body separate from the main CAD model. Try to make it a small section that can be printed quickly — aim for under an hour in print time.

3. **Design segment variations** if you want to test different tolerances on the feature in question. Each unit variation can be its own print or you can combine them into a single part to keep them organized.

4. **Print and test segment variations** to determine which variation fits the way you like it and best suits your part needs.

5. **Update the original model** with the desired dimensions tested with your variations and print out the full part.
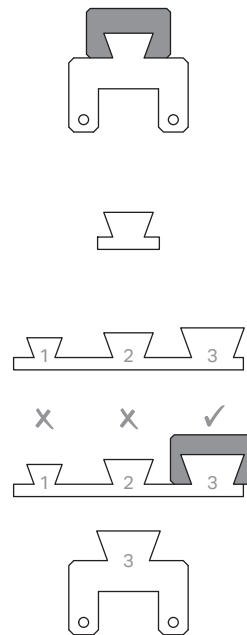
Tolerancing and clearances

Below are some recommended fits between printed parts. Specifics may change based on material and geometry. Listed dimensions are diametral, indicating the overall change in dimension between the two interfacing parts.

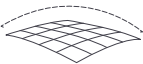| Press fit	Close fit	Free fit
0.00 mm - 0.05 mm (0.00" - 0.002")	0.05 mm - 0.10 mm (0.002" - 0.004")	0.10 mm - 0.20 mm (0.004" - 0.008")
Parts require some applied force via cold pressing to assemble.	Parts can be assembled or disassembled by hand with negligible clearance.	Parts can slide and/or rotate easily when assembled.
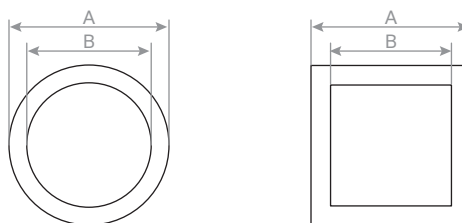
Diametral clearance = A - B

Understanding Matrix Materials

A composite material is a combination of two materials that, when combined, create a material to leverage benefits of both of its constituents. Each constituent material is distinct within the composite, so a mixture is not considered a composite material. Markforged 3D printers print in composites by laying continuous fibers into a plastic matrix material. By combining the surface and chemical properties of the matrix material with the strength, stiffness, and failure behavior of a fiber, you can create a composite 3D printed part optimized for the environment and the application you need.

Types of matrix materials

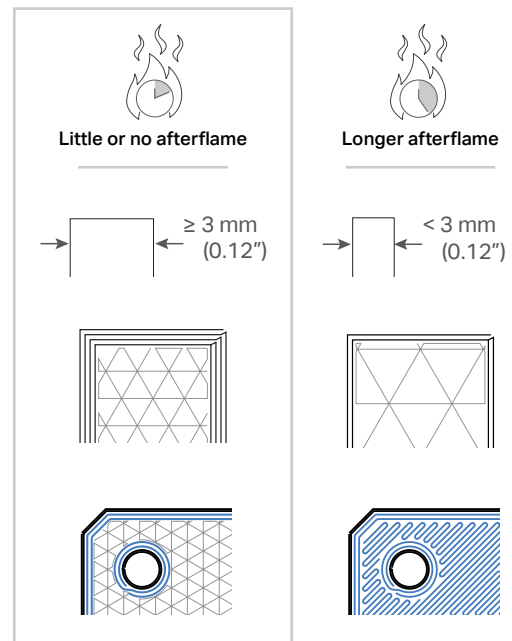All Markforged matrix materials are chemically resistant and reinforceable with any continuous fiber options.

	Onyx	Onyx FR	Onyx ESD	Nylon W
Properties	Strong, stiff material with heat-resistance and high dimensional stability	Flame-retardant version of Onyx with similar mechanical properties plus a UL94 V-0 rating down to 3mm of thickness	High-performance and static-dissipative version of Onyx that is stronger, stiffer, and meets stringent ESD-safe requirements	Tough material with smooth surface texture for repeated skin contact or workholding when handling highly polished surfaces
Aesthetic	Professional, matte-black finish	Professional, matte-black finish	Professional, deep matte-black finish	Semi-gloss white that can be painted or dyed
Printers	All Markforged 3D printers	Industrial Series printers	Industrial Series printers	Top-tier printers: Mark Two and X7 (No print head swap needed)

Designing for Onyx FR

Onyx FR beams have been UL tested and achieve a V-0 rating in the UL94 vertical flame test down to 3mm thickness. A material's UL rating is in part determined by the afterflame time, the time it takes for a flame to self-extinguish after the beam is lit. Materials rated at V-0 extinguish in under 10 seconds. However, the UL rating applies to the base material and does not account for how it is processed, so the flame performance of your part is dependent on its geometry and print settings. Therefore, a part might not be V-0 rated, but will still be flame retardant. You can follow these guidelines to decrease or eliminate your part's afterflame time:

Reducing afterflame time with Onyx FR:

1. **Feature size:** Onyx FR beams 3mm (0.12") and above extinguish in less than 10 seconds, so keep the important elements of your part thicker than this dimension. Small embossed or engraved features on thicker segments are fine to include.

2. **Walls and infill:** The more Onyx FR in your part, the higher its flame resistance. You can decrease the afterflame time by increasing the number of walls or infill density within your part.

3. **Fiber reinforcement:** Adding continuous fiber will increase the afterflame time of a part. Use fiber-efficient reinforcement practices to place continuous fibers where you need strength to limit the afterflame time. Follow strategic practices to reinforce most effectively and limit your fiber volume.

Little or no afterflame

Longer afterflame

≥ 3 mm (0.12")

< 3 mm (0.12")

Diving Deep into Fiber Reinforcement

Types of fiber

|	Carbon Fiber	Fiberglass	HSHT Fiberglass	Kevlar®
Properties	High strength-to-weight ratio, stiff	Sturdy, cost-effective	Sturdy, high heat deflection	Tough, impact-resistant
Ideal loading type	Constant loading	Intermittent loading	Constant loading at high temperatures	Impact loading
Failure behavior	Stiff until fracture	Bends until fracture	High energy absorption until fracture	Bends until deformation
Characteristics and advantages	Metal stiffness and strength, lightweight	Economical starting point, general-use fiber	Keeps strength at high temperatures	High deflection and impact resistance

Types of fiber fill

Concentric Fill

Concentric Fill lays fiber around the perimeter of a wall. This fill type mainly helps resist bending about the Z axis and strengthens the walls against deformation. You can specify how many fiber shells you want by changing the number of **CONCENTRIC FIBER RINGS**. You can edit the start point of the fiber by changing the **START ROTATION PERCENT** setting when viewing a 2D layer slice or group in **INTERNAL VIEW.**
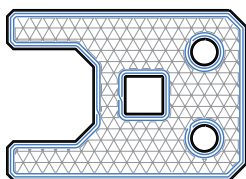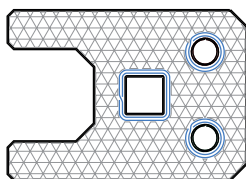

All walls

This type lays down fiber to reinforce both the outer shell and the inner holes, providing the reinforcement properties of both.
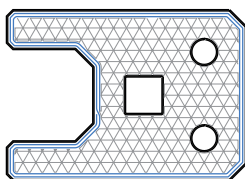
Outer shell only

This type only reinforces the outer walls of a part. This can be used to reinforce the part for bending or impact loads applied to the sides of the part.

Inner holes only

This type only reinforces the inside walls of a part. This can be used to strengthen bolt holes or cavities to improve load distribution when compressive or out-of axis torsional forces are applied to inner holes.

Isotropic fill

Isotropic fill is routes fiber back and forth in a zig-zag pattern to simulate the individual unidirectional layers of a traditional laminated composite. By default, subsequent Isotropic Fiber layers rotate the fibers by 45° to achieve unidirectional strength within a fiber group, but the **FIBER ANGLE** can be changed if needed. Layers of Isotropic Fill Fiber resist bending in the XY plane. In addition to the isotropic fill pattern, this option by default traces concentric rings around all walls to improve wall strength.

Diving Deep into Fiber Reinforcement

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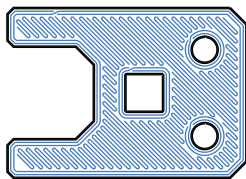
A brief composites fiber lesson

Imagine you are holding a piece of raw spaghetti by one of its ends. Under which type of load is it strongest? If you try to bend it, it snaps. If you try to compress it lengthwise by trying to push the two endpoints closer together, it also snaps. However, if you load it in tension by pulling on it, it can hold a decent load.

This is the theory behind working with continuous composite fibers. Whether you are printing them, winding them, or weaving them, continuous fibers are strongest when loaded in tension. Composite fiber materials like carbon fiber, Kevlar®, and fiberglass are known for their material properties in tension. The key is understanding where the fibers are loaded in tension, and how a given load can distribute amongst the local fibers.
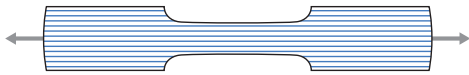
Tension

Fibers are strongest in tension, so a part loaded in tension should consist of fibers running up and down the length of the part, being "stretched" by the force. You can align fibers with your tensile forces with **CONCENTRIC FIBER** along ribs or with **FIBER ANGLES** when using **ISOTROPIC FIBER.**
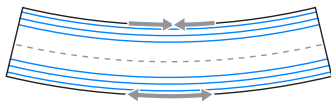
Bending

Beam Bending Theory shows that when a beam is bent, the inside face of the bend is loaded in compression, while the outside face of the bend is loaded in tension. By putting rigid materials on the extremes of a beam you reinforce it most effectively. This is why traditional composite layups consist of fiber panels on each face with a softer material on the inside, forming what is called a sandwich panel**.** To reinforce a part in bending, build a sandwich panel with **ISOTROPIC FIBER** panels if the neutral plane is in XY, or **CONCENTRIC FIBER** when bending around the Z axis.
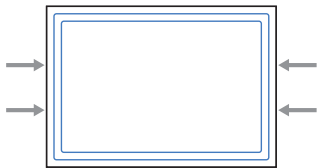
Compression

The key to dealing with compressive forces is in the force distribution. The fiber should serve as a scaffold beneath the load, able to distribute the load along the fiber's path. Side loads can be reinforced from compression with **CONCENTRIC REINFORCEMENT**. Vertical loads can be reinforced from compression using **ISOTROPIC REINFORCEMENT** on the upper and lower faces, and **CONCENTRIC REINFORCEMENT** between the two Isotropic panels to further support the load. This is especially helpful for supporting clamping forces from bolts.
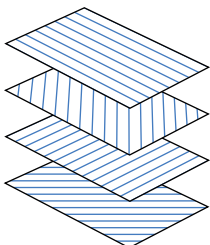
Important note:

Markforged 3D printers print composite parts that are effectively transverse isotropic. While isotropic materials have uniform material properties in all directions, transverse isotropic materials have one set of properties along an axis, and a different set on planes normal to that axis. This translates to 3D printed parts, in which the part strength on XY planes is stronger than the part strength along the Z axis, especially with continuous fibers. This is why it's important to consider print orientation during the design process.

Diving Deep into Fiber Reinforcement

How to think about reinforcing with continuous fibers
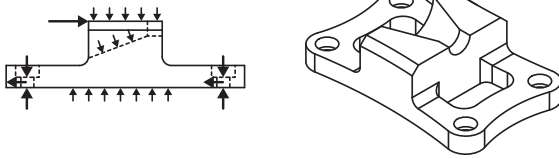
1. Identify loading conditions

Take a look at your design. Where will it undergo bending forces? Tensile forces? Compressive forces? If you're not sure, think about how forces will transmit through other parts — draw a diagram if you need to! This will help you to make an informed decision about your fiber routing strategy.

2. Determine print orientation

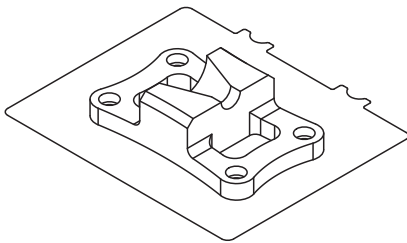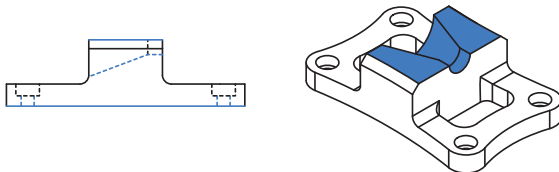What directions are the largest loads traveling in on your part? You want your part to be oriented such that these forces largely travel in plane with the print bed to load fibers in bending or tension. If you have many large forces spanning multiple axes, you may want to consider modifying the design or splitting it up into a few parts.

3. Determine reinforcement areas

Based on loading conditions, what surfaces or segments need to be strengthened? With that in mind, think about what types of reinforcement you will need to implement in those areas.
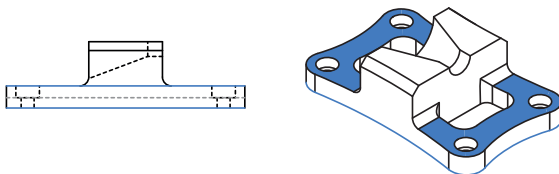
4. Balance fiber panels

If only one side of a part is reinforced, it may be prone to warping due to an uneven sandwich panel — if one face is strengthened and the other isn't, or if one face has a vastly different cross-section. If one layer group of your part is reinforced, balance the sandwich panel by reinforcing an equivalent layer group on the furthest substantial Z layer with a similar cross section.
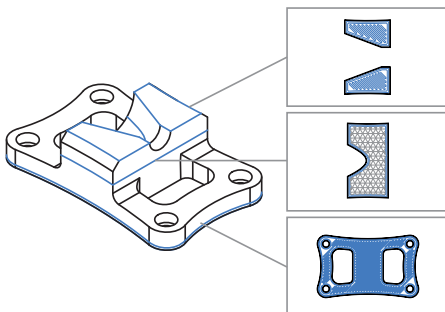
5. Confirm fiber pathing

Does fiber fit and travel through the areas you need it to? Can you trace continuous strands of fiber that route along the load paths and "brace" against the force? If not, you may need to adjust fiber settings or modify features so that fiber runs through the places you need it to. Remember that fiber groups requires at least four plastic roof and floor layers to print, so any faces that need reinforcement should start four layers offset from the closest roof or floor.

Diving Deep into Fiber Reinforcement

Basic reinforcement strategy: Shelling

Outlined below is a basic strategy for reinforcing a printed part. This strategy will ensure your part is generally strong and resistant to bending and impact forces on any axis. As described earlier, it's more important to reinforce the extremes of your part than the core, so we are going to walk you through how to "shell" a part for efficient strength all around.

1. Isotropic panels on furthest substantial Z layers

To maximize bending strength, create a sandwich panel with 2-4 layers of **ISOTROPIC FIBER** on the top and bottom planes of the part, excluding any small surface extrusions. The fiber layers should start above the four "floor" layers or end below the four "roof" layers of a given horizontal surface.

2. Isotropic panels on intermediary large geometry changes

Add 2-4 layers of **ISOTROPIC FIBER** below or above any surfaces that dictate large changes in part geometry, again accounting for four "roof" and "floor" layers.

3. Inner hole reinforcement for Z-axis bolt holes

Reinforce Z axis bolt holes with two rings of **CONCENTRIC FIBER**. Use **INNER HOLES ONLY** if you don't need side load reinforcement, or use **ALL WALLS** to encompass Step 4. This will distribute the compressive force applied by the bolt and creates a composite "sleeve" to resist any off-axis torsional loads the bolt experiences.

4. Outer-wall reinforcement for any side loads

To maximize bending strength about the Z axis and reinforce against side loads, reinforce the outer walls of the part with two rings **CONCENTRIC FIBER**. Use **OUTER SHELL ONLY** if you have no Z-axis bolt holes, or use **ALL WALLS** to encompass Step 3. This will also reinforce any holes with axes on the XY plane.

Diving Deep into Fiber Reinforcement

Specialized reinforcement strategies

If you need to address more specific loading conditions, you can employ different tactics to strengthen specific areas, reinforce certain part sections, or control fiber placement. Below are some unique additional strategies you can implement inside your part.
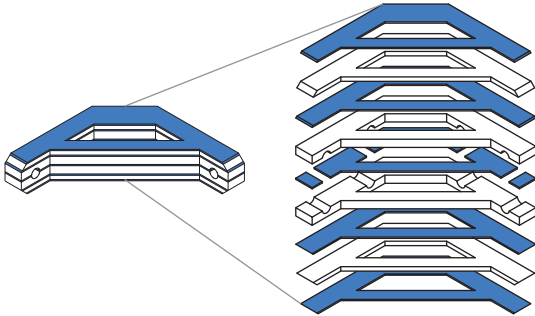

Fiber panel striping

For increased bending strength on the XY plane, you can add "stripes" of **ISOTROPIC FIBER** across multiple Z layers. This is most effective with thicker parts that have a fairly consistent or symmetric cross section, because Fiber striping creates multiple superimposed sandwich panels to further reinforce a part in bending.
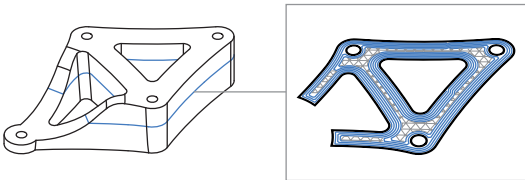

Directing fiber with ribs

You can route fiber in specific directions with reinforced ribs or cutouts that follow load paths from forces applied to your part. You can force the fiber to follow these load paths by applying **CONCENTRIC FIBER** to reinforce around the cutouts or walls.

90°

210°

330°
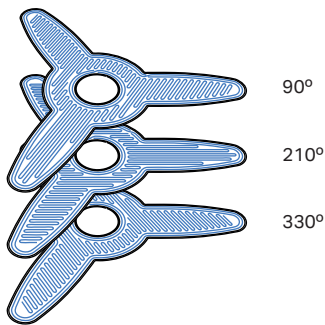
Using fiber angles to direct fibers

You can use the **FIBER ANGLES** tool to route the "zig-zag" of Isotropic Fibers in a certain direction. If you have the fibers routed in a specific direction to better align with the forces being applied to your part, you can manipulate the angle of this pattern. The default setting rotates the fill pattern by 45° each layer, but you can change that by putting a specific angle or pattern of angles in the Fiber Angles dialog box for any layer, any group of layers, or across the entire part.
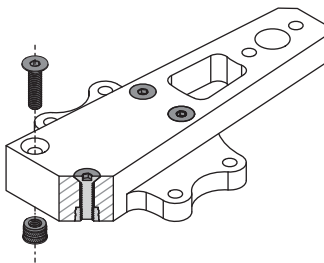
Achieving Z-axis strength

Clever design and reinforcement strategies allow you to achieve greater strength on multiple axes. Running a bolt through your part with fiber reinforcing the compressed surfaces can strengthen the part and prevent shear or tensile forces from splitting the part on layer lines. You can reinforce the area around the bolt with **CONCENTRIC FIBER — INNER HOLES ONLY** so that any of those forces distribute to the fiber in the form of bending forces.

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Design Guide
for 3D Printing
with Composites