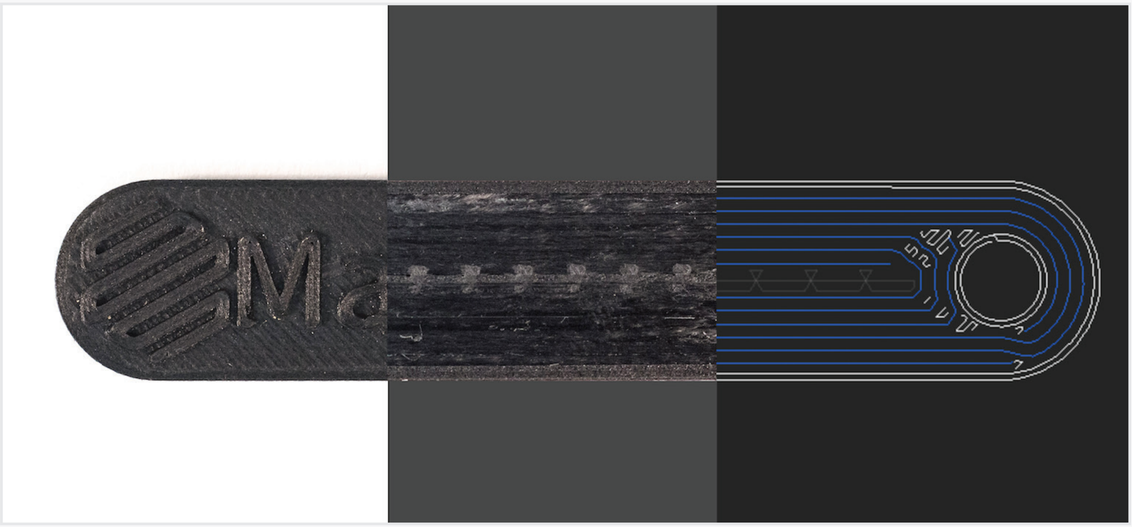
Guide to Leveraging Continuous Fiber for Strong 3D Printing

Strong 3D Printing

For the past few decades, the biggest roadblock to 3D printing has been materials. Many of the most common materials are weak and brittle, limiting 3D printing to modeling and fit prototyping. As the technology has advanced, so have its materials. Today 3D printing materials are better than ever. Prohibitively expensive materials that only multi-million dollar printers could produce are now becoming affordable. Tough nylons, stiff composites, and even metal materials are entering affordable price ranges for businesses and consumers alike. While stronger materials are available, proper use and education around those materials is equally important. Markforged printers are unique in their ability to lay continuous strands of carbon fibers inside 3D printed parts to achieve strengths comparable to metals. Here we'll discuss efficient fiber routing strategies for Markforged composite printers so you get the highest Return On Investment.

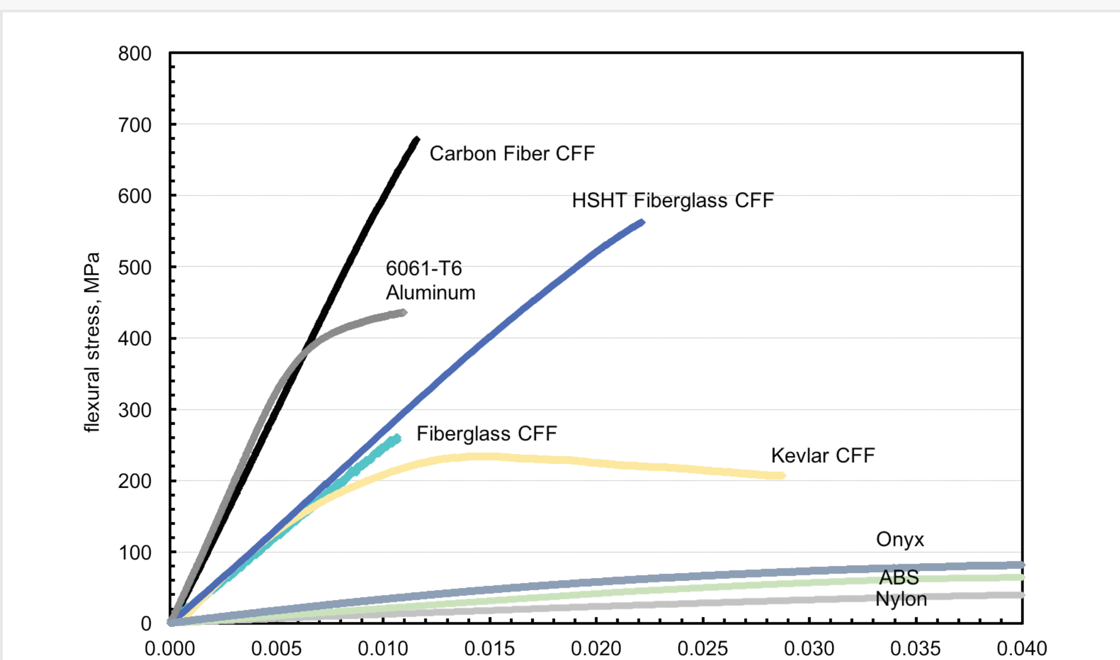
CONTINUOUS FIBER FABRICATION

Markforged has brought strong 3D printing down to an affordable level by creating Continuous Fiber Fabrication (CFF) 3D printing machines that lay continuous composite fibers like fiberglass, Kevlar, and carbon fiber inside 3D printed plastics to improve their strength properties. This makes functional prototyping a simple, expedient, and affordable process – for a company to prototype in this way it often takes an external machine shop multiple weeks lead time to make a single part, and as the number of versions increases so does the cost. Markforged 3D printers produce parts that are just as strong overnight.



A cutaway view of our carbon fiber reinforced sample part and its layout in our software. The printer lays continuous strands of carbon fiber inside the part to provide increased strength and stiffness.

The printer has two print nozzles: one that lays down a plastic filament, just like other Fused Filament Fabrication processes. This plastic forms the outer shell of the part as well as the internal matrix material. The second print nozzle lays down a continuous strand of a composite fiber on every layer with our Continuous Fiber Fabrication process. While many 3D printing materials consist of chopped carbon fiber filaments, the continuous composite fibers increase tensile and flexural strength by an order of magnitude.



The strength and toughness of Markforged continuous fibers is comparable to metals.

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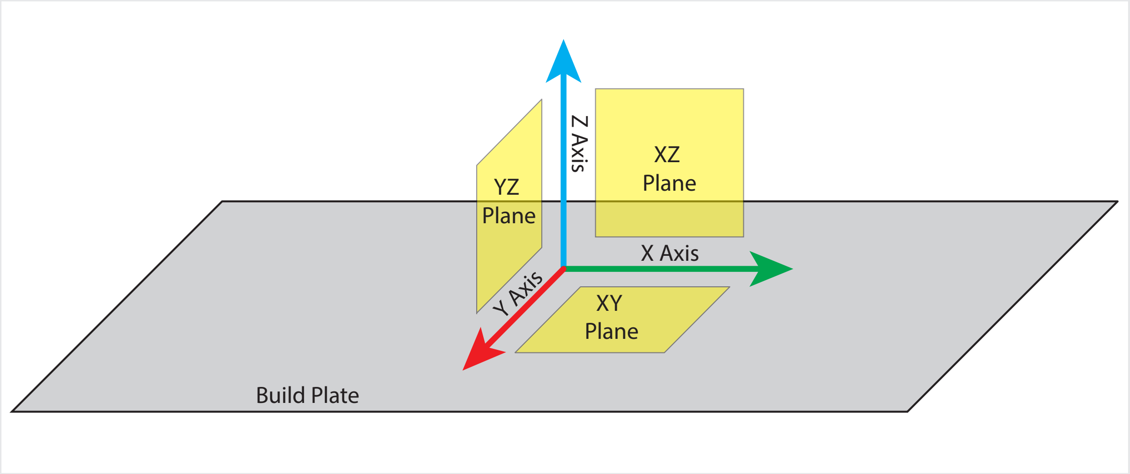
The Markforged ecosystem allows granular control of part reinforcement. On a layer-by-layer level, the fiber routing can be controlled, and different settings and options allow you to design in the strength profile you need to save material and cost.

Designing for 3D printing takes just as much work as designing for any other manufacturing process, and especially with the Markforged high-strength 3D printer, considering your manufacturing method is essential. There are some geometries and techniques that are very well suited for some processes and others not so much — we hope to encourage you to think about how you can use the unique fiber routing method efficiently and effectively to increase the strength of your 3D printed parts. Here we'll cover essential fiber routing techniques, what they do, and how you can set them up to save print time, material, and money

PART ORIENTATION

First, some standard naming conventions so that everyone is on the same page. This paper references to strength in different axes and planes frequently, so use this key as a guide:

Many 3D printers are weak in the Z axis. Any shear or tensile loading scenarios will cause the part to fracture. While Markforged materials are improved in this respect, the fiber is still laid down only on the XY plane. In general, parts that need strength in a specific direction should be orientated such that they make the most use of the continuous fibers. Below we'll cover how to use these effectively to improve strength around any of these reference geometries



A guide for axes and planes referenced in this paper.

FIBER FILL

Markforged printers give you the option to reinforce parts with two different fiber fill strategies: Isotropic Fiber or Concentric Fiber. You can apply these two options globally in the Part View page, or on a layer by layer basis in the Internal View page. Each fill type has its own strengths and weaknesses, which we describe below. If you don't have a printer and want to experiment with some of the tips listed below, get an Eiger trial to try these tactics out while you read.

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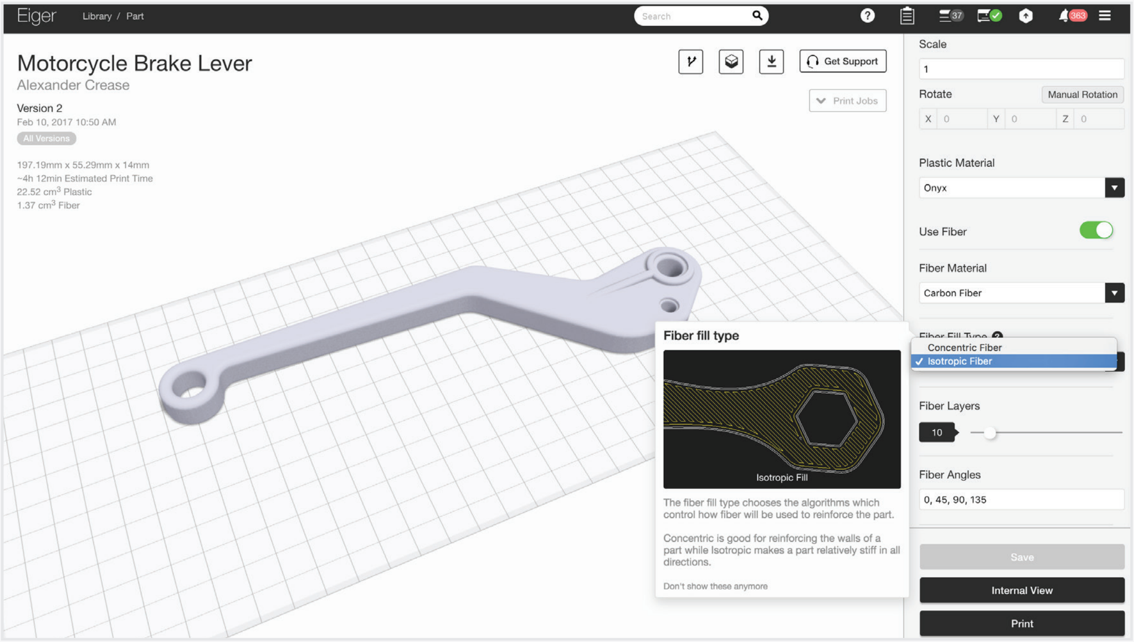
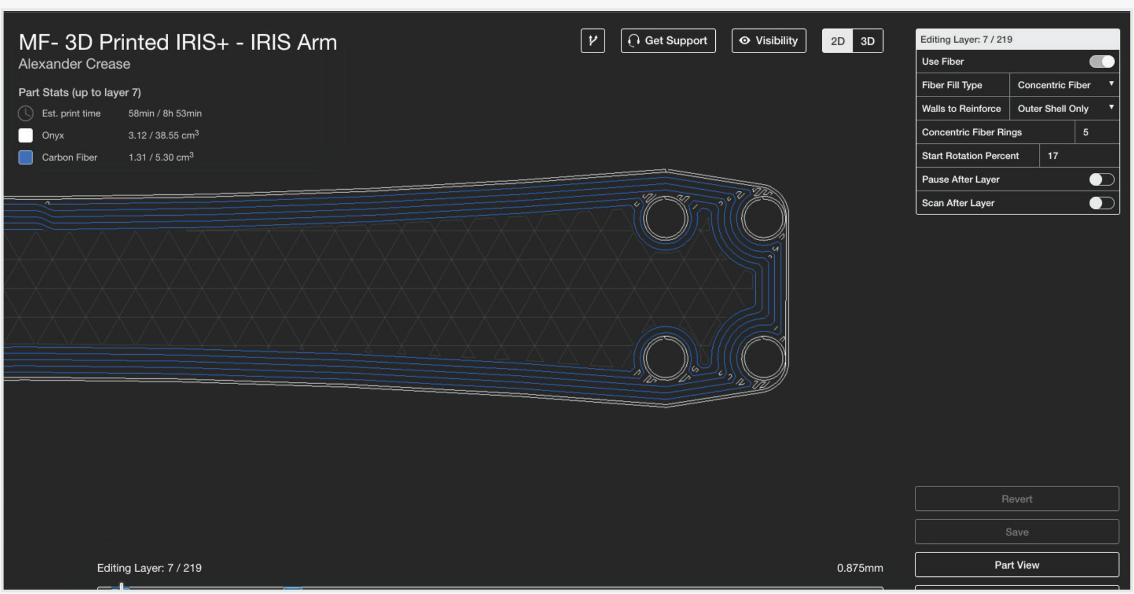


Reinforce using a selection of different continuous fiber fill types.

CONCENTRIC FILL REINFORCEMENT

Concentric Fill simply traces a specific number of shells within the walls of your part, which helps reinforce from bending around the Z axis. By doing so, essentially reinforces the walls of the part, preventing the walls from deforming.



A section of a drone arm reinforced with Concentric Fiber Fill.

In this fill type, the print head follows the outer curvature of the part as it spirals inwards, so the more complex that curvature is and the more rings you add, the longer it will take. When using concentric fill, you can specify how many rings of fiber you want tracing the outline of your part, so you have specific control over how much fiber you are using per layer. Our software also provides three different wall reinforcement options for concentric fill:

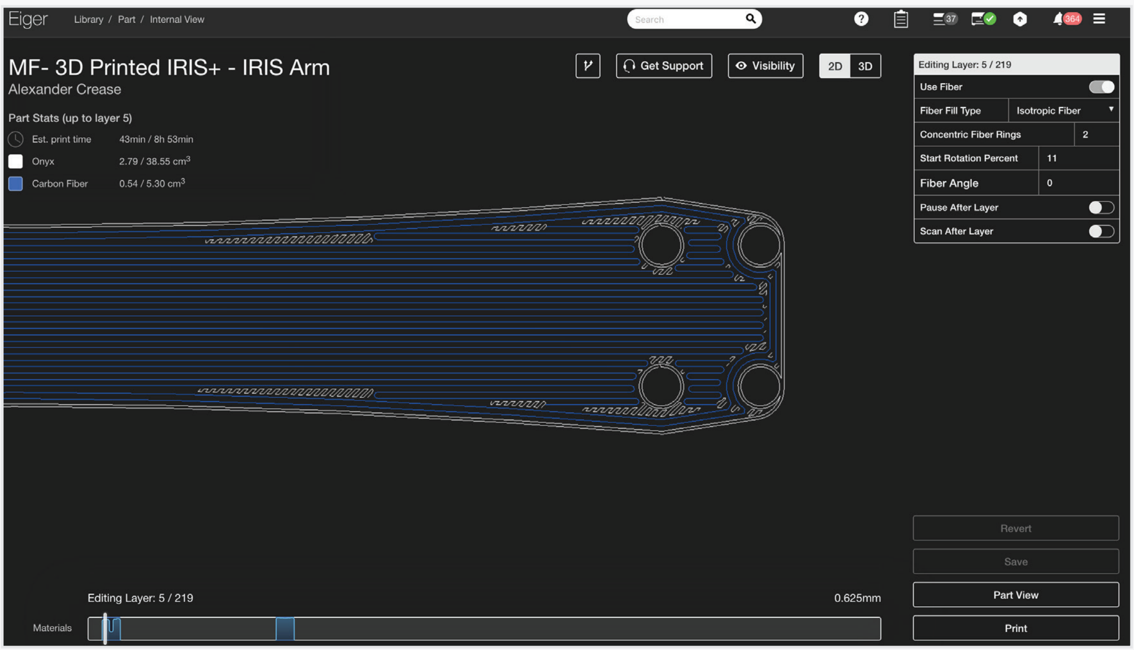
Outer Shell Only: Outer Shell Reinforcement only adds concentric rings to reinforce the outer perimeter of the part. This gives the part strength in bending around the Z axis by reinforcing the walls with parallel strands of fiber.

Inner Holes Only: Inner Hole Reinforcement adds concentric rings around all internal features of the part. It is an easy and material-efficient method to reinforce holes, cavities, and any other internal features.

All Walls: This setting adds the specified number of concentric rings to both the perimeter of the part and all internal features. This default setting combines the reinforcement strength of both Outer Shell and Inner Hole Reinforcement.

ISOTROPIC FILL REINFORCEMENT

The other reinforcement option is an Isotropic Fiber fill pattern — this simulates the individual unidirectional layers of a traditional laminated composite. The pattern effectively creates a unidirectional 'sheet' of fiber on each layer you apply it to by routing all fibers parallel to each other in a single angular orientation, with 180 degree turns when the path reaches the edge of the part. Subsequent Isotropic Fiber layers in a fiber group are automatically rotated by Eiger at 45 degree angles to the orientation of the fiber in the preceding layer, although custom orientation patterns are certainly possible, which we will go into below.



The drone arm now reinforced with Isotropic Fiber Fill.

The Isotropic Fiber fill pattern helps resist bending in the XY plane because any bending forces applied in that plane will generate a tensile load on at least some of the fibers, which are strongest in tension. Isotropic Fiber can also be used to set up sandwich panels to increase torsional strength on that plane, which will be covered later.

One thing you may notice is that isotropic fiber by default puts 2 concentric rings of fiber around the outside of the part. This ensures a smoothly reinforced external surface with the outermost fibers are always continuous and parallel to the edge of the part. While isotropic fiber is great for reinforcing the entire plane of each part, it is fiber- and time-expensive and it is not always necessary to create strong parts.

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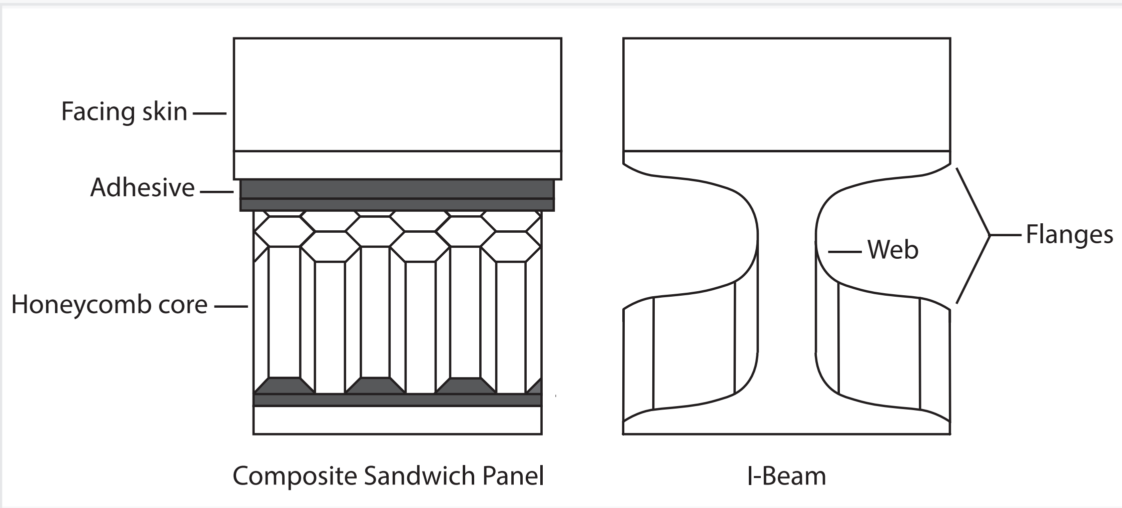
BASIC FIBER ROUTING TECHNIQUES

With these two fiber routing options in your toolbox, there are now many different reinforcement options that utilize and combine both options. The following techniques are simple tricks that can help you save money, materials, and print time by allowing you to reinforce only when and where you need it.

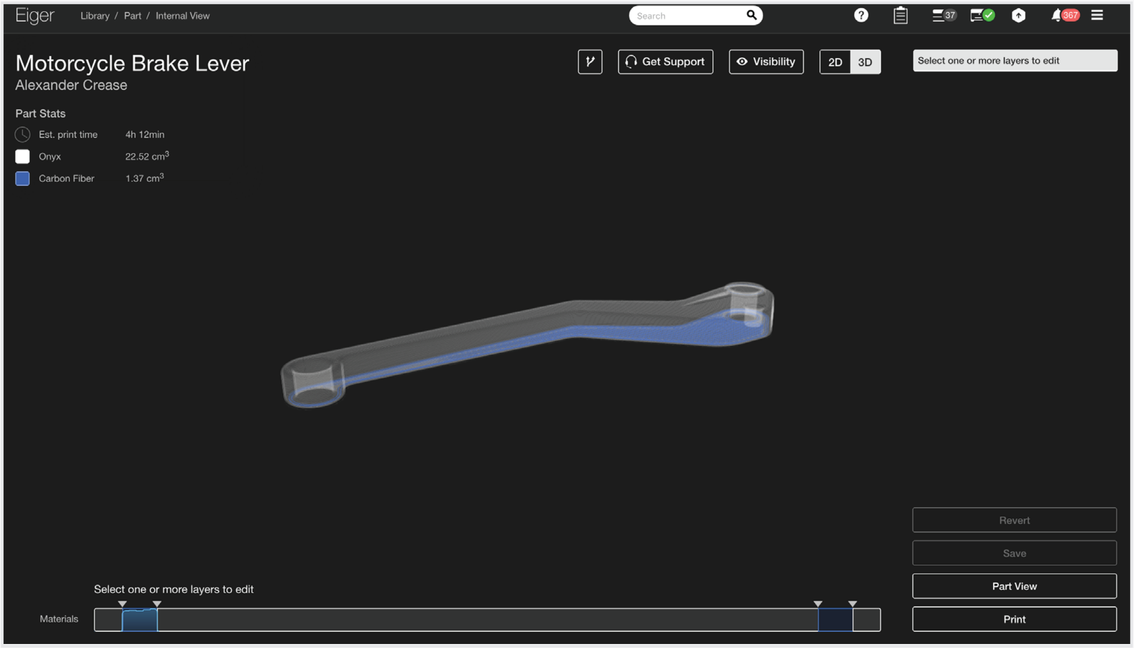
SINGLE SANDWICH PANEL

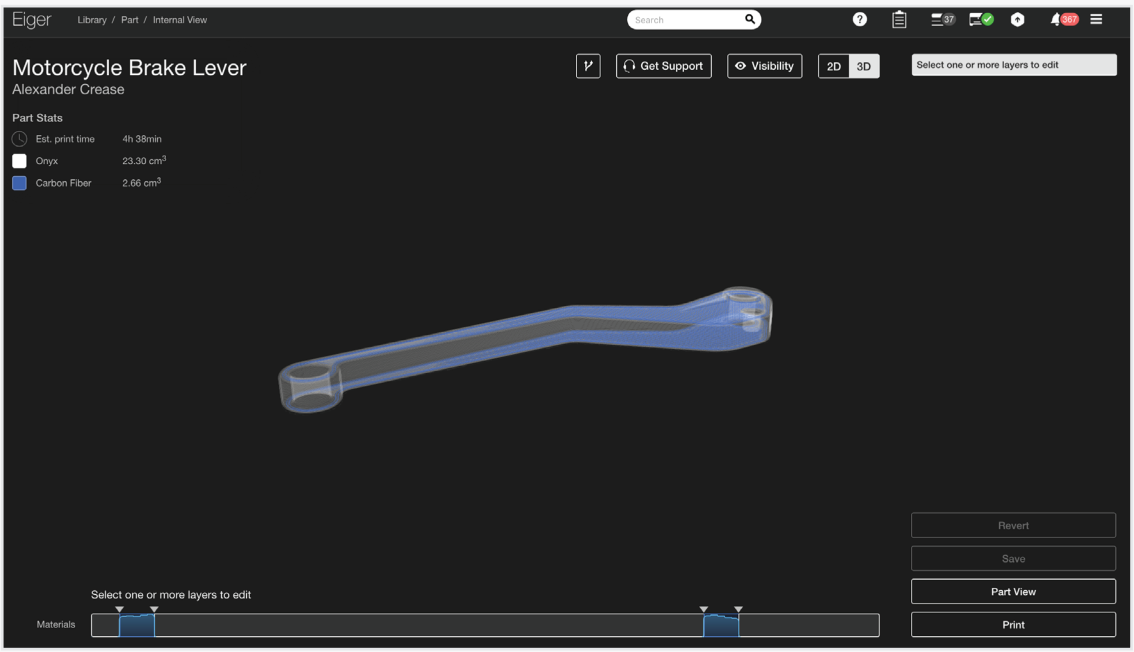
A sandwich panel is a common composite layup technique to reinforce for torsion around the surface that the composite sheet creates. As described in this blog post, a sandwich panel is the composite equivalent of an I-beam, with a stiff, strong material making up the top and bottom of a part — the top and bottom planes undergo the most bending stress so they are often the most reinforced. If you know that your part is going to encounter torsion on the XY plane, a sandwich panel will improve the part's torsional strength.



A sandwich panel, like an I beam, is primarily reinforced on the top and bottom to maximize strength and minimize weight.

Markforged software will automatically generate a sandwich panel once "Use Fiber" is selected. However, this should only be implemented if your part is vertically symmetrical, as it will lay fiber in the top and bottom few layers of your part. In the image below, note how the top of the brake lever has a small extrusion, so fiber needs to be manually added below the largest top surface to make an even sandwich panel. In general, it is best to have a sandwich panel consisting of layers with very similar cross sectional areas.





The sandwich panel on the brake lever needs to be balanced for effective flexural strength.

For the sandwich panel to be even, be sure that there are an equal number of isotropic layers on the top and bottom surfaces you wish to reinforce. If not, your part will be stronger in bending in one direction and not in another. This may result in breakage or warping more readily in one direction. The more layers of fiber you have on either side and the further apart the sandwich is, the stronger your part will be. Isotropic fiber layers in the center of your part will have less of an effect on the bending strength of the part, so entirely packing a part with fiber to provide strength in bending isn't necessary.

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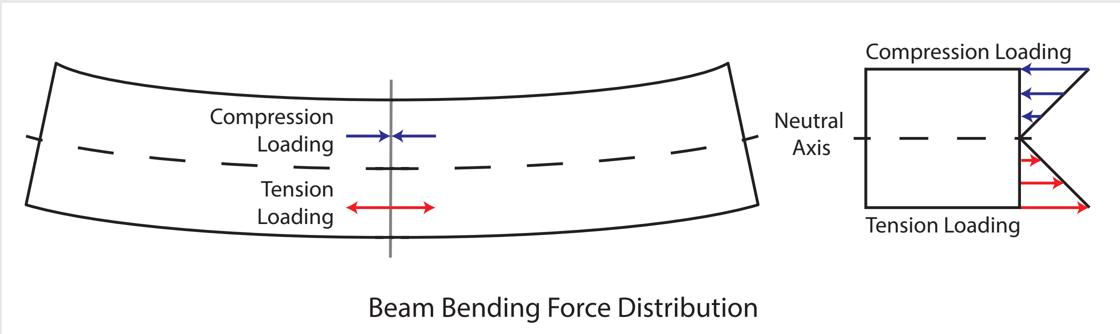


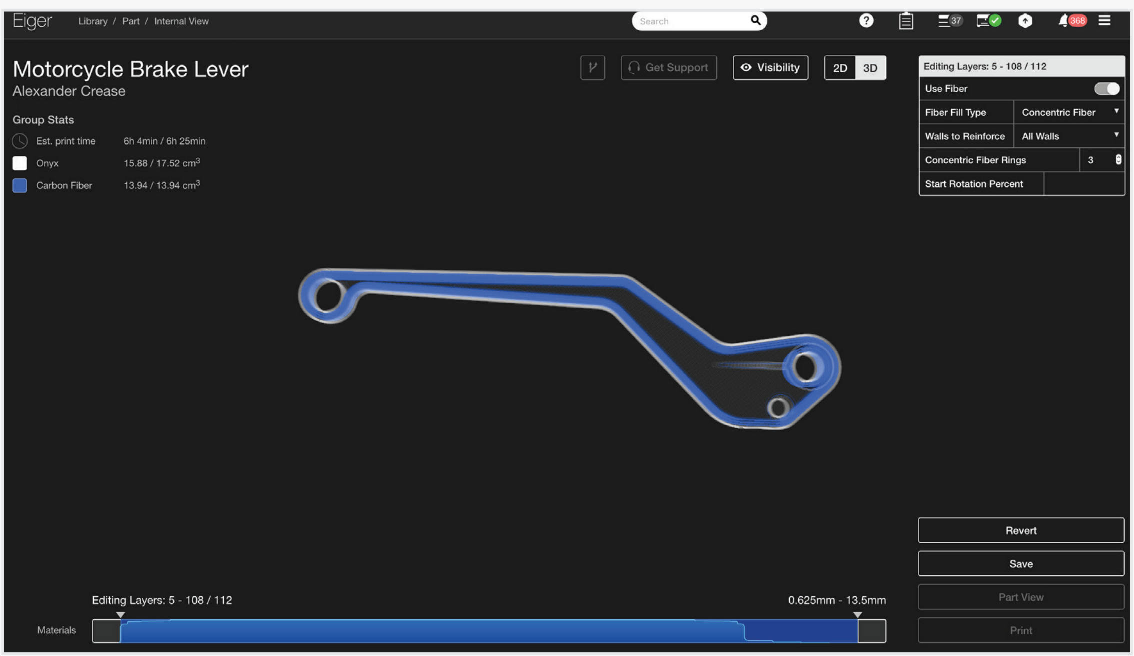
The distribution of bending stress on the profile of a beam. The highest loads from bending occur on the top and bottom faces of the beam, so these areas must be the most heavily reinforced.

FIBER PERIMETER

While sandwich paneling increases strength around the XY plane, creating a Fiber Perimeter will make your part stronger around the Z axis. By using the Concentric Fill option on every layer of your part, you can increase strength in bending around the Z axis. As I mentioned earlier, Concentric Fill reinforces the walls of your part, so creating a fiber perimeter within your part makes those walls much harder to bend. This is why many engineering materials take the form of C channels or tubes instead of blocks: to reduce weight but conserve strength.

To set up a Fiber Perimeter in your part, use concentric fill on the layers you wish to reinforce. By increasing the number of concentric rings or increasing the layers in which concentric rings are used, you can increase the strength of the part around the Z axis. The brake lever below will experience bending stress about the Z axis, so I have reinforced every layer with 3 rings of concentric fiber to maximize stiffness. Just like with sandwich

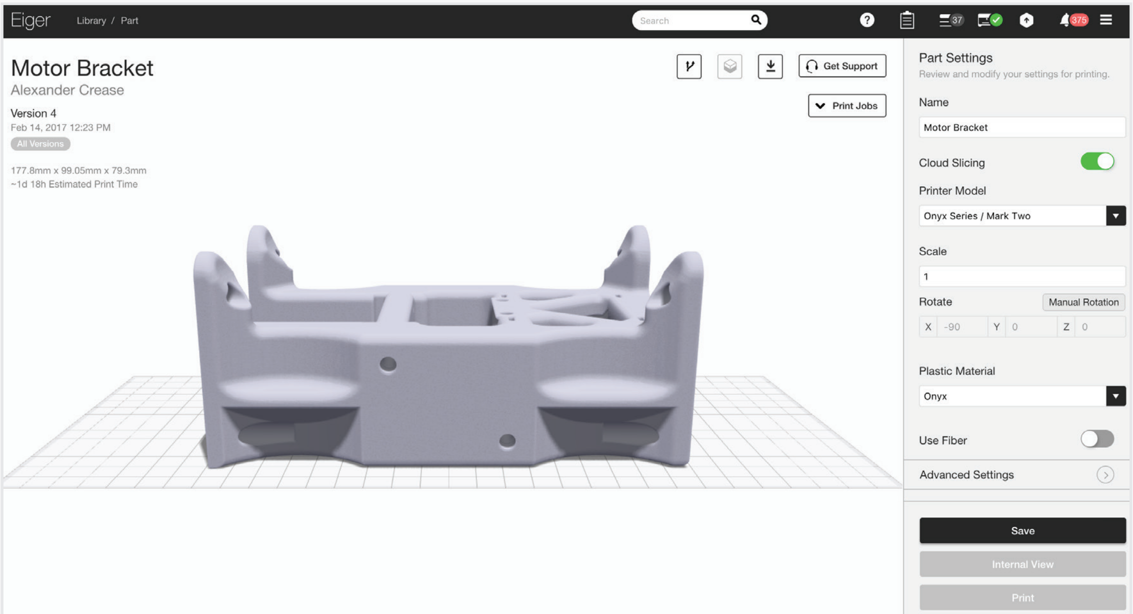
paneling, the middle of the part encounters the least bending stress, so the part doesn't need to be reinforced with rings all the way to the center.



The brake lever reinforced with concentric rings of fiber to improve flexural strength.

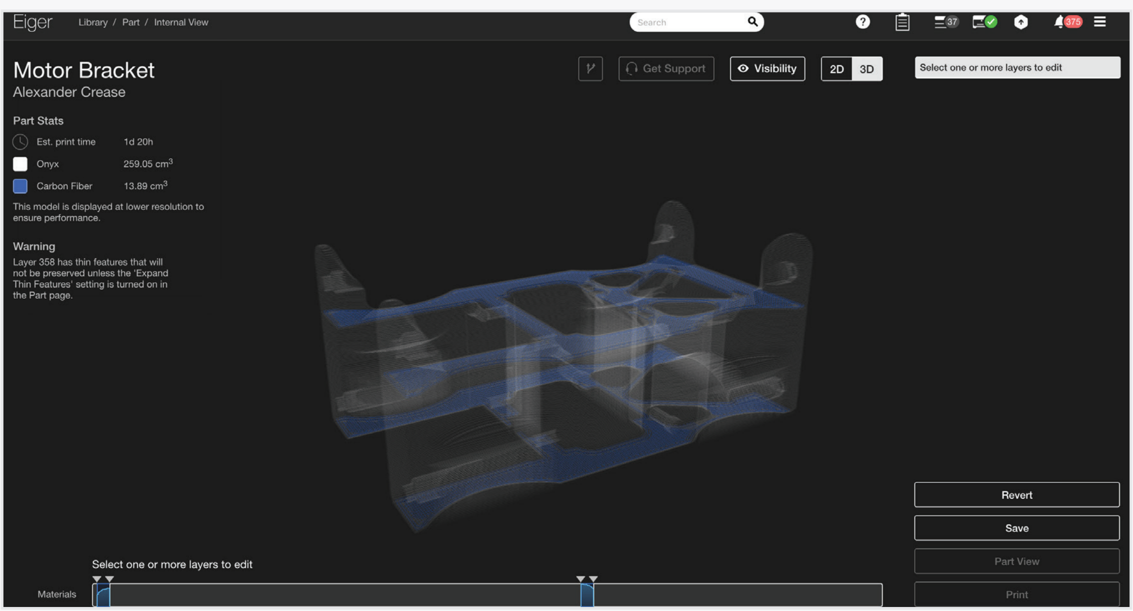
SHELLING

What if your parts need to have increased bending stiffness on each axis, or you don't quite know how they are going to be loaded? You can reinforce parts from flexing on every axis by combining these two techniques. With a sandwich panel on the top and bottom and shells of fiber in-between, the flexural strength of your part is improved on every axis. This motor bracket for a heavy-duty robotics application needs to be strong, but may experience loads from any direction, so something like this needs to be heavily reinforced from all sides.



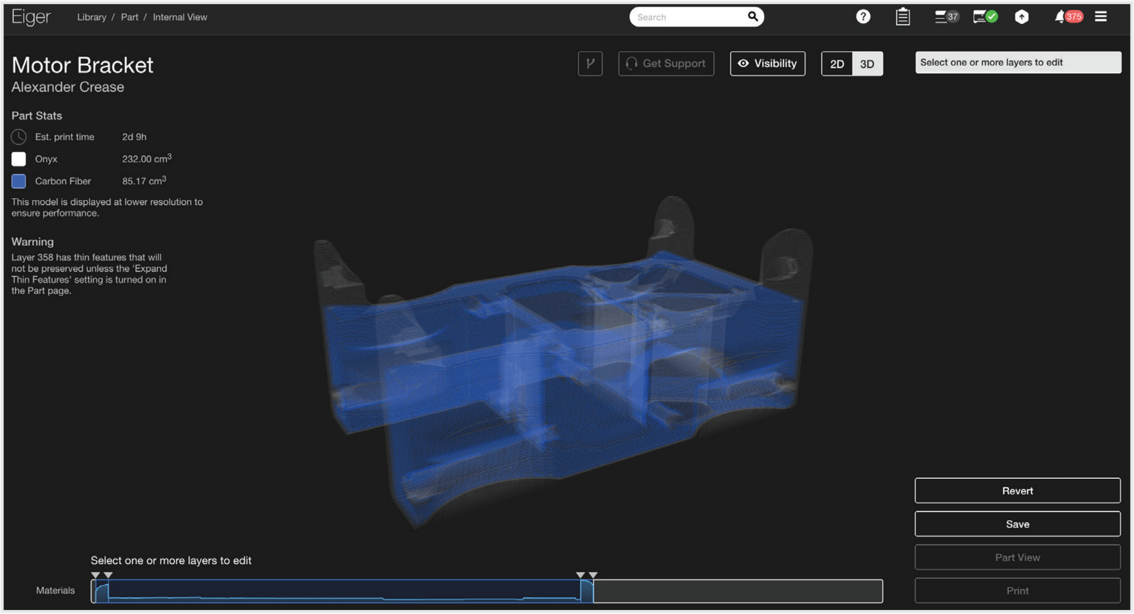
A large motor bracket for a high strength application.

This motor bracket needs to be a very robust part, so a 20-layer isotropic fiber sandwichPanel was added (10 per side). However, because of the bolt-hole extrusions on the top of the part, the upper panel must be adjusted and placed beneath the true top face.



The motor bracket with basic sandwich panel reinforcement.

The bar at the bottom allows you to control different sections of fiber and displays how much fiber each layer has, normalized to the largest amount of fiber. In the image above, you can see two sections of fiber reinforcement for a simple isotropic sandwich panel. Now you can select the center region between the two "panels", create a group, and set the fiber routing to Concentric Fiber Fill with 2 concentric fiber rings.



Concentric fibers between the sandwich paneling creates a reinforcing shell of fibers inside the part.

This part is now efficiently reinforced in bending through use of both Isotropic and Concentric Fiber Fill. By understanding how each type of fiber fill configuration reinforces a part, you can develop simple tricks like this to improve part performance and print time without wasting unnecessary fiber.

Reinforcing 3D printed parts breaks the boundaries of 3D printing as merely a tool for modeling and prototyping, putting industrial strength parts right into your hands. While a Markforged 3D printer can create metal-strength parts with its unique Continuous Fiber Fabrication process, designing and laying your fiber routing paths efficiently ensures further production cost and time savings. With these reinforcement tactics, you can create strong, cost effective, precision parts without breaking the bank.

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