# Markforged

## Same Day. Strong Parts.

Designed to print parts with the strength of metal, the Mark Two Industrial Strength 3D Printer™ is the world's first 3D printer capable of printing continuous carbon fiber, Kevlar®, and fiberglass. Using a patent pending Continuous Filament Fabrication (CFF™) print head alongside a Fused Filament Fabrication (FFF) print head, the Mark Two can create functional parts by combining our specially tuned nylon with continuous fiber filaments.

## 3D Print Parts:

- With a higher strength-to-weight ratio than 6061-T6 Aluminum
- Up to 27x stiffer than ABS
- Up to 24x stronger than ABS

## Mechanical Properties of Continuous Fibers

| Property | Test Standard | Carbon CFF | Kevlar® CFF | Fiberglass CFF | HSHT Glass CFF |
|---|---|---|---|---|---|
| **Tensile Strength (MPa)** | ASTM D3039 | 700 | 610 | 590 | 600 |
| **Tensile Modulus (Gpa)** | ASTM D3039 | 54 | 27 | 21 | 21 |
| **Tensile Strain at Break (%)** | ASTM D3039 | 1.5 | 2.7 | 3.8 | 3.9 |
| **Flexural Strength (MPa)** | ASTM D790* | 470 | 190 | 210 | 420 |
| **Flexural Modulus (GPa)** | ASTM D790* | 51 | 26 | 22 | 21 |
| **Flexural Strain at Break (%)** | ASTM D790* | 1.2 | 2.1 | 1.1 | 2.2 |
| **Compressive Strength (MPa)** | ASTM D6641 | 320 | 97 | 140 | 192 |
| **Compressive Modulus (GPa)** | ASTM D6641 | 54 | 28 | 21 | 21 |
| **Compressive Strain at Break (%)** | ASTM D6641 | 0.7 | 1.5 | n/a | n/a |
| **Heat Deflection Temperature (%)** | ASTM D648 Method B | 105 | 105 | 105 | 150 |

*Measured by a method similar to ASTM D790

Dimensions and Construction of Fiber Composite Test Specimens

- Test plaques used in this data are fiber reinforced unidirectionally (0° Plies)
- Tensile test specimens:
  9.8 in (L) x 0.5 in (H) x 0.048 in (W) (CF composites),
  9.8 in (L) x 0.5 in (H) x 0.08 in (W) (GF and aramid composites)
- Compressive test specimens: 5.5 in (L) x 0.5 in (H) x 0.085 in (W) (CF composites), 5.5 in (L) x 0.5 in (H) x 0.12 in (W) (aramid and GF composites)
- Flexural test specimens: 3-pt. Bending, 4.5 in (L) x 0.4 in (W) x 0.12 in (H)
- Heat-deflection temperature at 0.45 MPa, 66 psi (ASTM D648-07 Method B)

Tensile, Compressive, Strain at Break, and Heat Deflection Temperature data were provided by an accredited 3rd party test facility. Flexural data was prepared by MarkForged, Inc. The above specifications were met or exceeded.

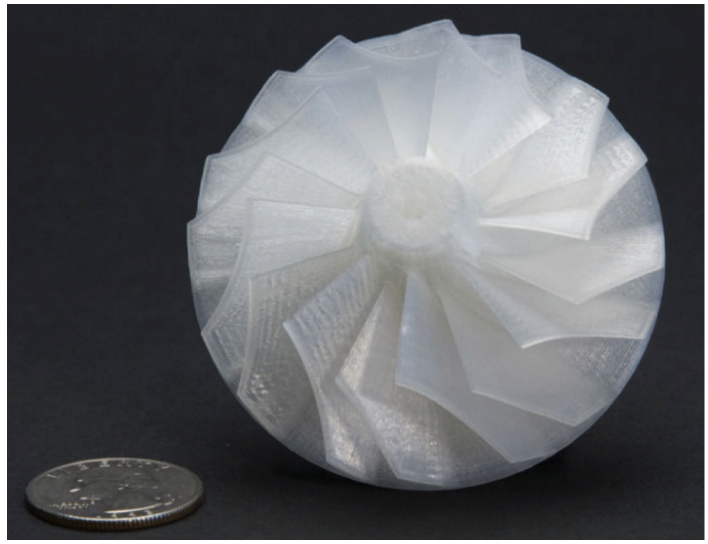
The Mark Two Industrial Strength 3D Printer is capable of printing a wide variety of fiber reinforcement patterns creating both anisotropic and quasi-isotropic ply constructions. This data sheet gives reference and comparison material properties using one possible set of standards-compliant ASTM plaques printed with a production Mark Two 3D printer.

However, part and material performance will vary by ply design, part design, end-use conditions, test conditions, build conditions, and the like.

# Mechanical Properties of Nylon

| Property | Test Standard | Nylon |
|---|---|---|
| Tensile Strength (MPa) | ASTM D638 | 54 |
| Tensile Modulus (GPa) | ASTM D638 | 0.94 |
| Tensile Strain at Break (%) | ASTM D638 | 260 |
| Flexural Strength (MPa) | ASTM D790* | 32 |
| Flexural Modulus (GPa) | ASTM D790* | 0.84 |
| Flexural Strain at Break (%) | ASTM D790* | N/A |
| Heat Deflection Temperature (ºC) | ASTM D648<br>Method B | 49<br>140† |

*Measured by a method similar to ASTM D790
†Heat deflection temperature of a beam with less than 10% HSHT Glass added, see below for details



Dimensions and Construction of Plastic Test Specimens
- Tensile test specimens: ASTM D638 type IV beams
- Flexural test specimens: 3-pt. Bending, 4.5 in (L) x 0.4 in (W) x 0.12 in (H)
- Heat-deflection temperature at 0.45 MPa, 66 psi (ASTM D648-07 Method B)
- Flexural Strain at Break is not available because nylon does not break before the test ends

# Design Principles for Bending

Markforged CFF™ technology **reinforces** 3D plastic parts with 10x stronger and 20x stiffer continuous fibers.

The above Material Properties therefore are **combined** in a part automatically by our Eiger software (although users may also customized the fiber distribution per layer).

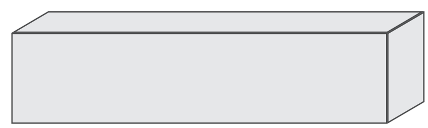
In automatic mode, Markforged's Eiger software defaults to creating embedded Sandwich Panels — well-known reinforced structures widely used in aerospace and construction that provide excellent **bending** performance.

Overall part stiffness and strength, represented by tensile and compressive Material Properties above, depends very much upon fiber content, and is strongly related to the amount of fiber the user chooses for a part.

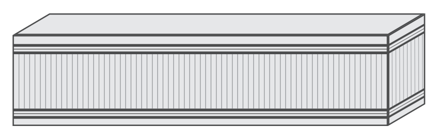
However, per engineering sandwich theory, **flexural** or bending performance tends to benefit **strongly** from **modest** reinforcement in a sandwich panel form (see images on the right).

For this reason, we separately present **flexural values** and **heat deflection temperature** values for exemplary beams.

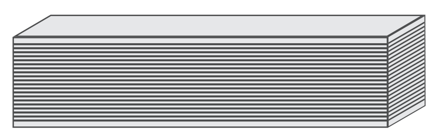
For more information, please our more detailed "Thermomechanical Stability" white paper.



**127 layer Nylon FFF Beam:**
(not to scale)
Heat Deflection: 49 °C



**127 layer HSHT Sandwich Beam:**
(not to scale)
117 layers nylon,
10 layers HSHT Glass CFF (~10% by vol.)
Heat Deflection: 140 °C



**127 layer HSHT Filled Beam:**
(not to scale)
2 layers Nylon,
125 layers HSHT Glass CFF:
Heat Deflection: 150 °C