Markforged

Same Day. Strong Parts.

Designed to strong, high quality, uncompromised parts, Markforged 3D Printers™ are the world's first 3D printers 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, Markforged printers 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 (°C)	ASTM D648 Method B	105	105	105	150
Izod Impact — notched (J/m)	ASTM D256-10 Method A	958	1873**	2603	3117

*Measured by a method similar to ASTM D790
**Two samples measured instead of 5

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.

With the exception of the OnxyOne, Markforged Industrial Strength 3D Printers are 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 Markforged 3D printer.

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

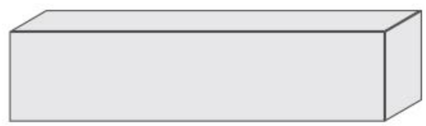
HAWK RIDGE SYSTEMS

Mechanical Properties of Nylon

Property	Test Standard	Tough Nylon	Onyx
Tensile Modulus (GPa)	ASTM D638	0.94	1.4
Tensile Stress at Yield (MPa)	ASTM D638	31	36
Tensile Strain at Yield (%)	ASTM D638	27	25
Tensile Stress at Break (MPa)	ASTM D638	54	30
Tensile Strain at Break (%)	ASTM D638	260	58
Flexural Strength (MPa)	ASTM D790*	32	81
Flexural Modulus (GPa)	ASTM D790*	0.84	2.9
Flexural Strain at Break (%)	ASTM D790*	n/a	n/a
Heat Deflection Temperature (°C)	ASTM D648 Method B	49 140†	145
Izod Impact — notched (J/m)	ASTM D256-10 Method A	1015	334

*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



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

Design Principles for Bending

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

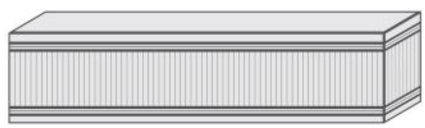
The above Material Properties therefore are **combined** in a part automatically by our Eiger software (although users may also customized the fiber distribution per layer).

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.

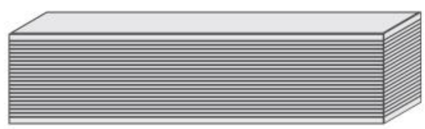
Overall part stiffness and strength, represented by tensile and compressive Material Properties above, depends very much upon fiber content, and is strongly related to the amount of fiber the user chooses for a part.

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



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

Hawk Ridge Systems is a global leader in engineering design and manufacturing solutions. Innovative 3D software applications include SOLIDWORKS 3D CAD design, CAMWorks manufacturing software and 3D Printing solutions.

Orinda • Santa Clara • Mountain View • Costa Mesa • Ontario • Ventura • Woodland Hills • Seattle • Portland • Las Vegas
Reno • Calgary • Edmonton • British Columbia • Toronto • Winnipeg
US: (877) 266-4469 • CAN: (866) 587-6803 • hawk@hawkridgesys.com • www.hawkridgesys.com