MATERIAL DATASHEET

Composites

Plastic Matrix	Test (ASTM)	Onyx	Nylon
Tensile Modulus (GPa)	D638	1.4	0.94
Tensile Stress at Yield (MPa)	D638	36	31
Tensile Strain at Yield (%)	D638	25	27
Tensile Stress at Break (MPa)	D638	30	54
Tensile Strain at Break (%)	D638	58	260
Flexural Strength (MPa)	D790[1]	81	32
Flexural Modulus (GPa)	D790[1]	2.9	0.84
Heat Deflection Temp (°C)	D648 B	145	49
Izod Impact - notched (J/m)	D256-10 A	330	1000
Density (g/cm³)	—	1.2	1.1

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)

All Markforged machines are equipped to print Onyx. Nylon is a specialized material that can only be printed on the Mark Two and X7. Machines that print Onyx cannot also print Nylon due to machine conditioning.

Markforged parts are primarily composed of plastic matrix. Users may add one type of fiber reinforcement in each part, enhancing its material properties.

1. Measured by a method similar to ASTM D790. Thermoplastic-only parts do not break before end of Flexural Test.

Fiber Reinforcement	Test (ASTM)	Carbon	Kevlar®	Fiberglass	HSHT FG
Tensile Strength (MPa)	D3039	800	610	590	600
Tensile Modulus (GPa)	D3039	60	27	21	21
Tensile Strain at Break (%)	D3039	1.5	2.7	3.8	3.9
Flexural Strength (MPa)	D790[1]	470	190	210	420
Flexural Modulus (GPa)	D790[1]	51	26	22	21
Flexural Strain at Break (%)	D790[1]	1.2	2.1	1.1	2.2
Compressive Strength (MPa)	D6641	320	97	140	192
Compressive Modulus (MPa)	D6641	54	28	21	21
Compressive Strain at Break (%)	D6641	0.7	1.5	—	—
Heat Deflection Temp (°C)	D648 B	105	105	105	150
Izod Impact - notched (J/m)	D256-10 A	960	2000	2600	3100
Density (g/cm³)	—	1.4	1.2	1.5	1.5

Dimensions and Construction of Fiber Composite Test Specimens:

- Test plaques used in these 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 Kevlar® 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) (Kevlar® 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 were prepared by Markforged, Inc. These represent typical values.

Markforged tests plaques are uniquely designed to maximize test performance. Fiber test plaques are fully filled with unidirectional fiber and printed without walls. Plastic test plaques are printed with full infill. To learn more about specific testing conditions or to request test parts for internal testing, contact a Markforged representative.

Part and material performance will vary by fiber layout design, part design, specific load conditions, test conditions, build conditions, and the like.

MATERIAL DESCRIPTIONS

Composites

Printing Methods

Plastic Matrix

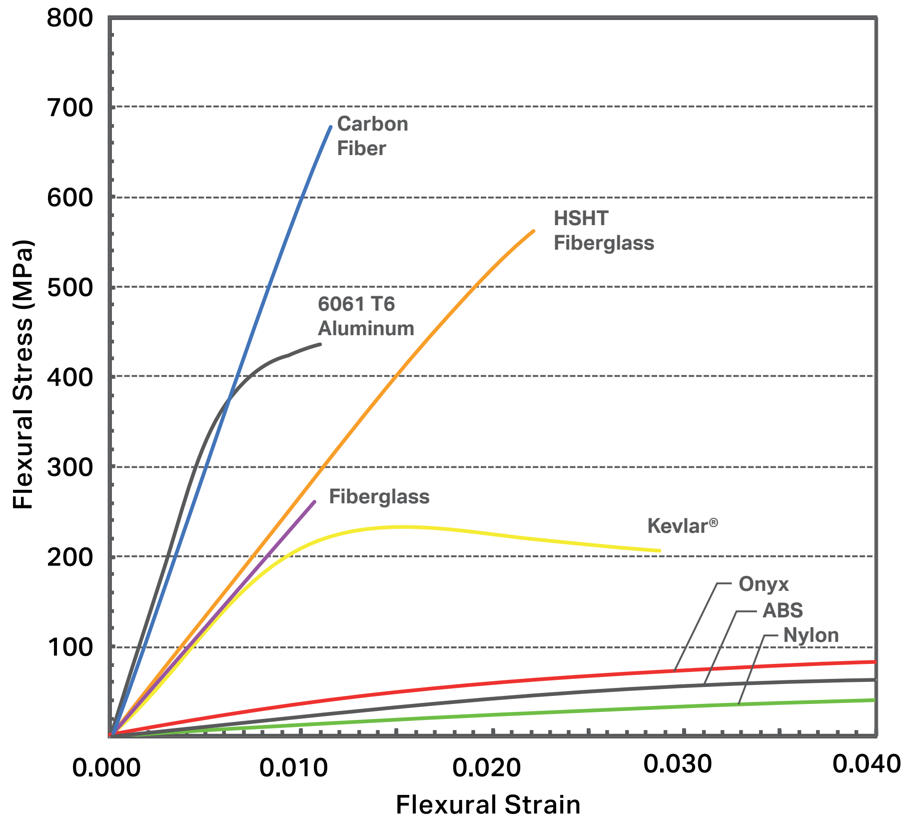
In Fused Filament Fabrication (FFF), the printer heats thermoplastic filament to near melting point and extrudes it through its nozzle, building a plastic matrix layer by layer. Markforged prints all thermoplastics by this method.

Onyx Nylon

Fiber Reinforcement

Continuous Filament Fabrication (CFF) is our unique technology that adds fiber reinforcement to printed parts. Within our thermoplastic matrix, Markforged uses proprietary technology to lay down continuous long-strand fiber. Users can control the layers reinforced, amount, orientation, and type of reinforcing fiber.

Fiberglass Carbon Fiber Kevlar® HSHT Fiberglass



Materials

Onyx Plastic

Engineering Grade Thermoplastic

Onyx yields stiff, strong, and accurate parts. Already 1.4 times stronger and stiffer than ABS, Onyx can be reinforced with any continuous fiber. Onyx sets the bar for surface finish, chemical resistivity, and heat tolerance.

Flexural Strength	**81 MPa**
Flexural Stiffness	**2.9 GPa**

Fiberglass Fiber

Reinforced Fiber Strength

Fiberglass is our entry level continuous fiber, providing high strength at an accessible price. 2.5 times stronger and eight times stiffer than Onyx, Fiberglass reinforcement results in strong, robust tools.

Flexural Strength	**210 MPa**
Flexural Stiffness	**22 GPa**

Carbon Fiber Fiber

Aluminum Strength. Half the Weight.

Carbon Fiber has the highest strength to weight ratio of our reinforcing fibers. Six times stronger and eighteen times stiffer than Onyx, Carbon Fiber reinforcement is commonly used for parts that replace machined aluminum.

Flexural Strength	**470 MPa**
Flexural Stiffness	**51 GPa**

Nylon Plastic

Tough Flexible Thermoplastic

Nylon parts are flexible, impact-resistant and can be reinforced with any Markforged continuous fiber. The material works best in applications that require increased flexibility or low working friction.

Flexural Strength	**32 MPa**
Flexural Stiffness	**0.84 GPa**

Kevlar® Fiber

Lightweight, Durable, and Strong

Kevlar® possesses excellent durability, making it optimal for parts that experience repeated and sudden loading. As stiff as fiberglass and much more ductile, it's best used for end of arm tooling.

Flexural Strength	**190 MPa**
Flexural Stiffness	**26 GPa**

HSHT Fiberglass Fiber

Strength at High Temperatures

High Strength High Temperature (HSHT) Fiberglass exhibits Aluminum strength and high heat tolerance. Five times as strong and seven times as stiff as Onyx, it's best used for parts loaded in high operating temperatures.

Flexural Strength	**420 MPa**
Flexural Stiffness	**21 GPa**

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.

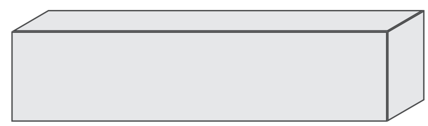
Mechanical Properties of Nylon

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.

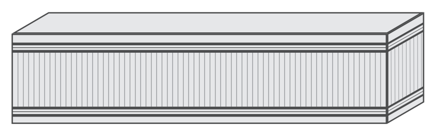
The above Material Properties therefore are **combined** in a part automatically by our Eiger software (although users may also customized the fiber distribution per layer).

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.

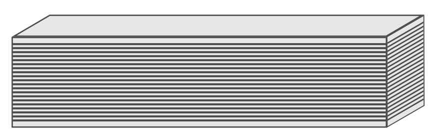
Overall part stiffness and strength, represented by tensile and compressive Material Properties above, depends very much upon fiber content, and is strongly related to the amount of fiber the user chooses for a part.

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