

# Composites

Plastic Matrix	Test (ASTM)	Onyx	Onyx FR	Nylon W
Tensile Modulus (GPa)	D638	1.4	1.3	1.7
Tensile Stress at Yield (MPa)	D638	36	29	51
Tensile Strain at Yield (%)	D638	25	33	4.5
Tensile Stress at Break (MPa)	D638	30	31	36
Tensile Strain at Break (%)	D638	58	58	150
Flexural Strength (MPa)	D790 <sup>1</sup>	81	79	50
Flexural Modulus (GPa)	D790 <sup>1</sup>	3.6	4.0	1.4
Heat Deflection Temp (°C)	D648 B	145	145	41
Flame Resistance	UL94	—	V0 <sup>2</sup>	—
Izod Impact - notched (J/m)	D256-10 A	330	—	110
Density (g/cm <sup>3</sup> )	—	1.2	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 composite machines are equipped to print Onyx. Nylon White is available on the Mark Two and X7. Onyx FR is available on X3, X5, and X7.

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.

2. Onyx FR at a thickness of 3mm achieves UL94 V0 rating from a third-party UL-certified lab.

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 <sup>1</sup>	540	240	200	420
Flexural Modulus (GPa)	D790 <sup>1</sup>	51	26	22	21
Flexural Strain at Break (%)	D790 <sup>1</sup>	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/cm <sup>3</sup> )	—	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 FG 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, Flexural, and

Heat Deflection Temperature data were provided by an accredited 3rd party test facility. 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. All customer parts should be tested in accordance to customer's specifications.

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

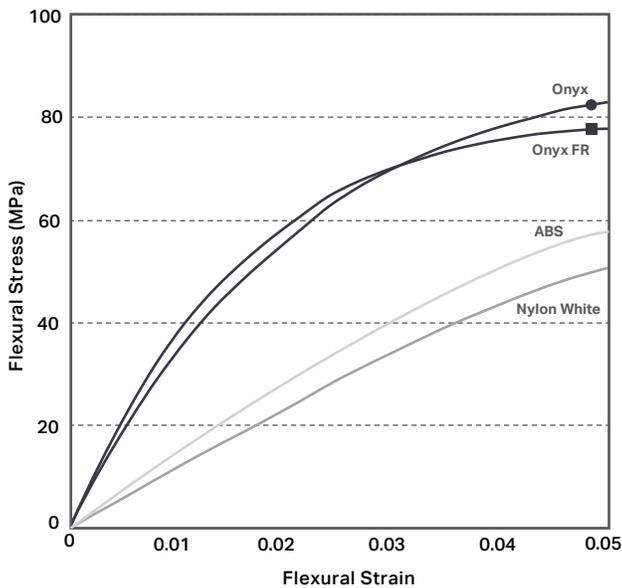
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# Composites

Markforged composite printers use a base plastic matrix reinforced with continuous fibers. Combining the materials during printing yields composite parts far stronger, stiffer, and more robust than conventional 3D printed plastics.

## Plastic Matrix

In Fused Filament Fabrication (FFF), a printer heats thermoplastic filament to near melting point and extrudes it through its nozzle, building a plastic matrix layer by layer. Plastics can be reinforced by any one type of fiber.



● **Onyx** Flexural Strength: 81 MPa

Onyx is a chopped carbon fiber reinforced nylon. It's 1.4 times stronger and stiffer than ABS and can be reinforced with any continuous fiber. Onyx sets the bar for surface finish, chemical resistivity, and heat tolerance.

■ **Onyx FR** Flexural Strength: 79 MPa

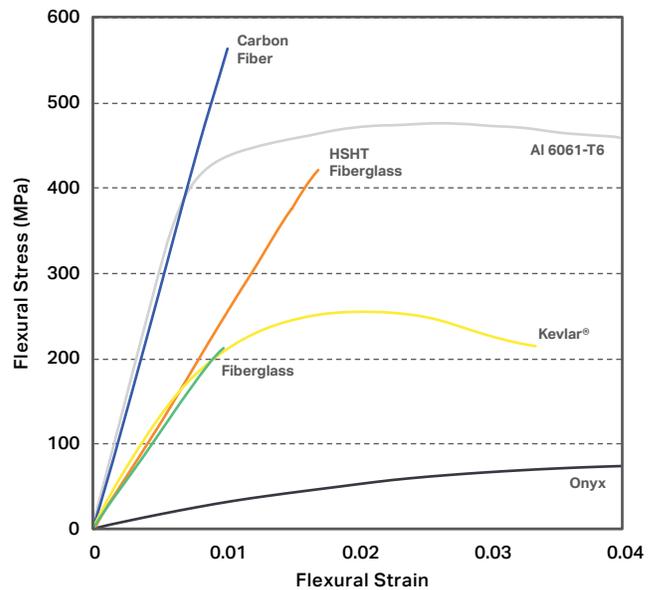
Onyx FR achieves V0 rating on the UL94 flammability test while possessing similar mechanical properties to Onyx. It's best for applications in which flame retardancy, light weight, and strength are required.

● **Nylon White** Flexural Strength: 51 MPa

Nylon White parts are smooth, non-abrasive, and easily painted. They can be reinforced with any continuous fiber and work best for non-marring work holding, repeated handling, and cosmetic parts.

## Fiber Reinforcement

Continuous Filament Fabrication (CFF) is proprietary technology that reinforces plastic printed parts with continuous fibers on each layer of a part. Users can control the layers reinforced, amount, orientation, and type of reinforcing fiber.



● **Carbon Fiber** Flexural Strength: 540 MPa

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.

● **Fiberglass** Flexural Strength: 200 MPa

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.

● **Kevlar®** Flexural Strength: 240 MPa

Kevlar® possesses excellent durability, making it optimal for parts that experience repeated and sudden loading. As stiff as fiberglass and much more ductile, it can be used for a wide variety of applications.

● **HSHT Fiberglass** Flexural Strength: 420 MPa

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.