Markforged

Markforged

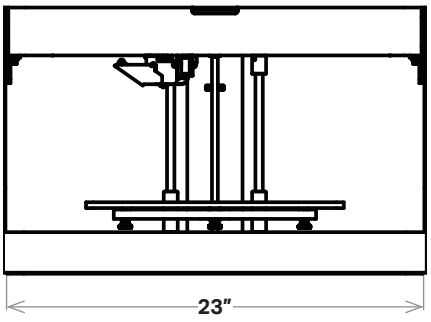
PRODUCT SPECIFICATIONS

Mark Two

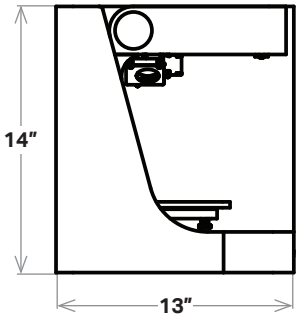
Replace machined aluminum tooling—jigs, jaws, and fixtures—with stronger parts for a fraction of the price. The Mark Two combines our unique continuous carbon fiber reinforcement with workhorse reliability for versatile parts with 26x the strength of ABS, ready same-day for use straight off the printer.

Printer Properties	**Process**	Fused filament fabrication, Continuous Filament Fabrication
	Build Volume	320 x 132 x 154 mm (12.6 x 5.2 x 6 in)
	Weight	16 kg (35 lbs)
	Machine Footprint	584 x 330 x 355 mm (23 x 13 x 14 in)
	Print Bed	Kinematic coupling — flat to within 160 µm
	Extrusion System	Second-generation extruder, out-of-plastic detection
	Power	100–240 VAC, 150 W (2 A peak)
Materials	**Plastics Available**	Onyx, Nylon White
	Fibers Available	Carbon fiber, fiberglass, Kevlar®, HSHT fiberglass
	Tensile Strength	800 MPa (25.8x ABS, 22.2x Onyx) *
	Flex Modulus	51 GPa (24.8x ABS, 14.2x Onyx) *
Part Properties	**Layer Height**	100 µm default, 200 µm maximum
	Infill	Closed cell infill: multiple geometries available
Software	**Supplied Software**	Eiger Cloud (Other options available at cost)
	Security	Two-factor authentication, org admin access, single sign-on

FRONT VIEW



SIDE VIEW



* Continuous carbon fiber data. **Note:** All specifications are approximate and subject to change without notice.

MATERIAL DATASHEET

Composites

Markforged

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[1]	81	79	50
Flexural Modulus (GPa)	D790[1]	3.6	4.0	1.4
Heat Deflection Temp (°C)	D648 B	145	145	41
Flame Resistance	UL94	—	V-0[2]	—
Izod Impact - notched (J/m)	D256-10 A	330	—	110
Density (g/cm^3)	—	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 is UL 94 V-0 Blue Card certified down to a thickness of 3mm.

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]	540	240	200	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/cm^3)	—	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, and Heat Deflection Temperature data were provided by an accredited 3rd party test facility. Flexural data was 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. 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.

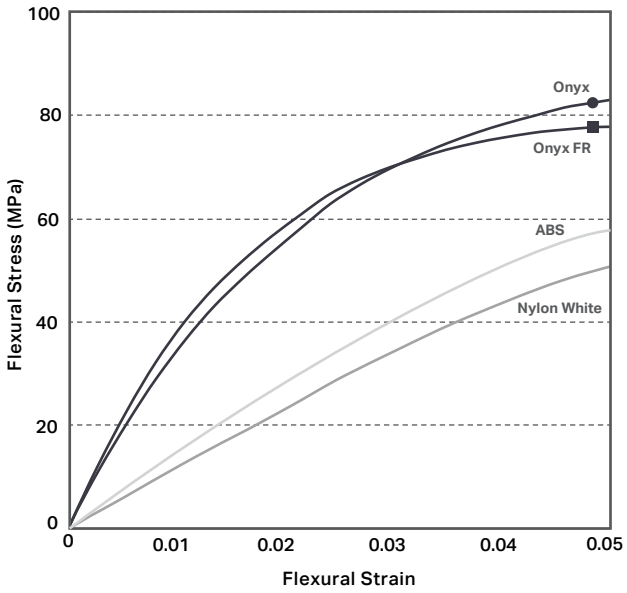
MATERIAL DESCRIPTIONS

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

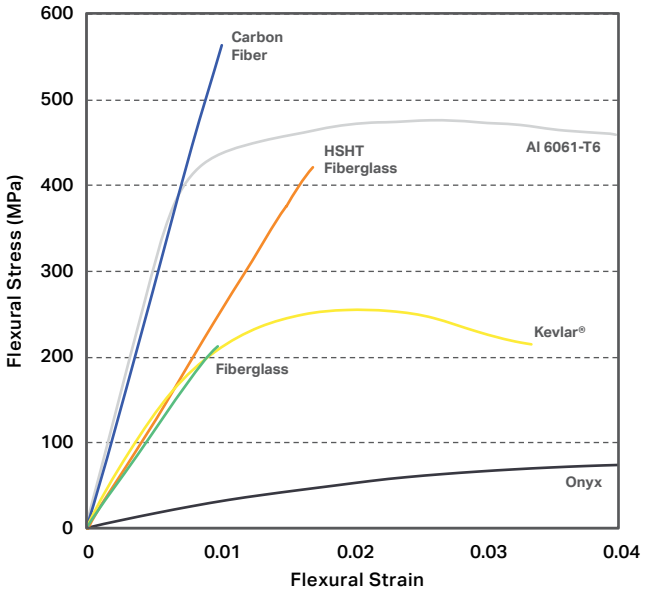
Onyx FR is a Blue Card certified UL94 V-0 material that possesses similar mechanical properties to Onyx. It's best for applications in which flame retardancy, light weight, and strength are required.

Nylon White — Flexural Strength: 50 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.

CASE STUDY

Wärtsilä

INDUSTRY	Marine and Energy Technology
APPLICATION	Tools and Fixtures
LOCATION	Vaasa, Finland and Trieste, Italy
CUSTOMER SINCE	2018

WÄRTSILÄ

Markforged

CASE STUDY

Wärtsilä

Four Markforged Printers, Two Countries: How Wärtsilä Made the First 3D Printed CE-Certified Lifting Tool

75%
TOTAL WEIGHT SAVINGS

100,000
EUROS SAVED IN TOOLING

960kg
TESTED LIFTING CAPACITY

240kg
CERTIFIED LIFTING CAPACITY

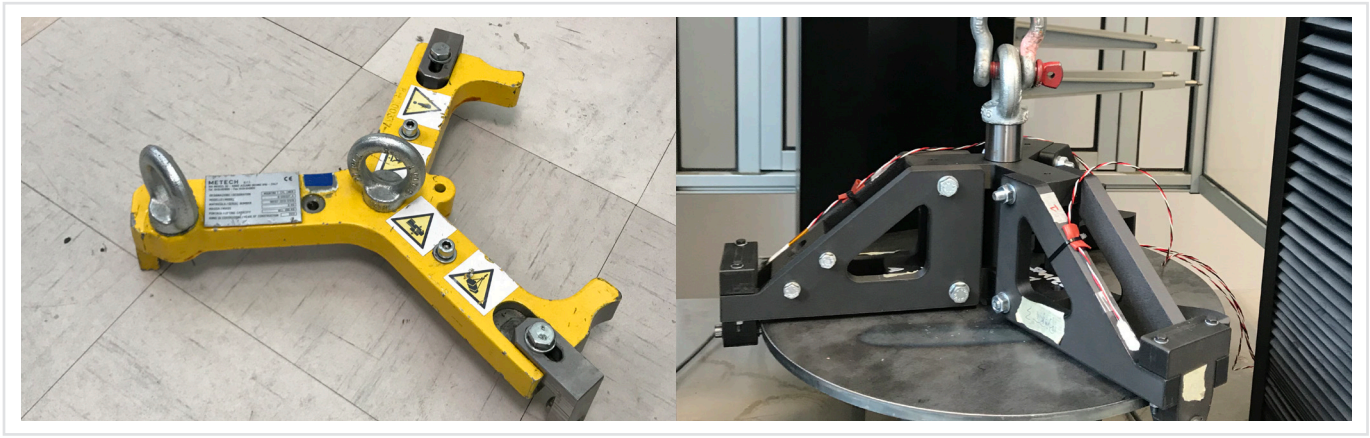
The Challenge

Wärtsilä is a global leader in smart technologies and complete lifecycle solutions for the marine and energy markets, with a portfolio of products that spans from engines to propulsion and renewable solutions. The Finnish factory in Vaasa and Italian factory in Trieste oversee the manufacturing of large engines that power a third of the world's largest cargo ships. The teams often need to fabricate tools to solve problems and optimize the efficiency of both the field and factories, and usually have to rely on third-party suppliers to manufacture them.

One such example is a lifting tool, which is critical to building and servicing large engines. The tool is a custom piece of hardware that allows them to move immensely heavy engine parts such as pistons. These lifting tools are critical as they can make lifting operations more efficient during the manufacturing process, and help engineers perform maintenance at the facility or on cargo ships. To interface with the complex features of their engines, many of the tools have unique mating features.

Wärtsilä usually machines its lifting tools out of solid steel, but found the resulting tools to be too expensive, too time-intensive to manufacture, and too heavy for people to use and transport. The teams are also unable to make quick design changes when needed. Each cost and weight increase has a significant impact when scaled across hundreds of tools — especially when the tool is needed to service or perform maintenance on parts in a large commercial ship where space is limited.

> **"The potential to cut costs is really significant. If you're going to save at least 1,000 Euros per tool, it's a straight benefit."**
>
> JUHO RAUKOLA,
> INNOVATION EXPERT (ADDITIVE MANUFACTURING), WÄRTSILÄ



The original lifting tool (L) was machined out of solid steel and weighed 75% more than its 3D printed replacement (R).

WÄRTSILÄ

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The Solution

Engineers at Wärtsilä had been using Markforged carbon fiber 3D printers since mid-2018 to solve similar problems, and had already made several tools for their factories. The Trieste and Vaasa teams decided they wanted to expand to a larger and more industrial printer to increase throughput, so they purchased an Industrial Series X7 printer for their Italian facility.

Working alongside Markforged, they redesigned the lifting tool for additive manufacturing. The new design included splitting the tool into a number of parts to best leverage continuous carbon fiber reinforcement and enabled the lifting tool to lift a 240 kilogram engine piston on the first try. "I think everybody was actually pretty shocked about the performance," said Juho Raukola, Innovation Expert (Additive Manufacturing) at Wärtsilä. The maximum weight the lifting tool can lift is 960 kilograms without deformation — however in manufacturing situations, the safety factor of four needs to be recognized. The team also worked alongside international certification agency Bureau Veritas to define a process to certify the tools. The tool was put through various tests and inspections, resulting in the first 3D printed CE-certified lifting tool — a huge achievement for the company.

Wärtsilä's embracement of additive manufacturing has already more than paid off, with the additive manufacturing team estimating that in just eight months they have saved over €100,000 in tooling alone, which they believe can scale with more Markforged printers in more facilities around the world.

Juho and his team are already on the road to freeing themselves from third-party suppliers, meaning they will no longer have to wait for anyone when fabricating tools for their facilities. "We don't have to work to someone else's schedule," said Juho. "And the beauty of 3D printing is that each design can then be printed anywhere at any time through distributed manufacturing, even on the ships Wärtsilä helps to maintain and service."

> **"This will enable Wärtsilä to speed up the introduction of new products with faster, cheaper, and safer tool creation."**
>
> GIUSEPPE SARAGÒ,
> DIRECTOR, MANUFACTURING EXCELLENCE, WÄRTSILÄ

The tool is capable of lifting up to 960kg with a safety factor of four.

Looking Ahead

With three Markforged carbon fiber printers, and now a Metal X 3D printer capable of printing in various industrial metals. Wärtsilä is far from done when it comes to adopting an additive manufacturing approach to solving problems. From tool holders and measuring tools to customer-facing production parts, engineers are now empowered to search for new 3D printed applications all around the production floor. "If we want another tool for production, with a specific customer design, it's not four to six weeks like it was conventionally, but it's now really a couple of days," said Giuseppe. "We are able to answer the need and fulfill the need faster."

WÄRTSILÄ

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MARKFORGED APPLICATION SPOTLIGHT

THERMOSET MOLD

STRENGTH AND PRECISION— Humanetics uses a Markforged X7 to print molds for thermoset plastics.

EXTREME ENVIRONMENT — Each mold must withstand significant clamping force while heated to 220º F.

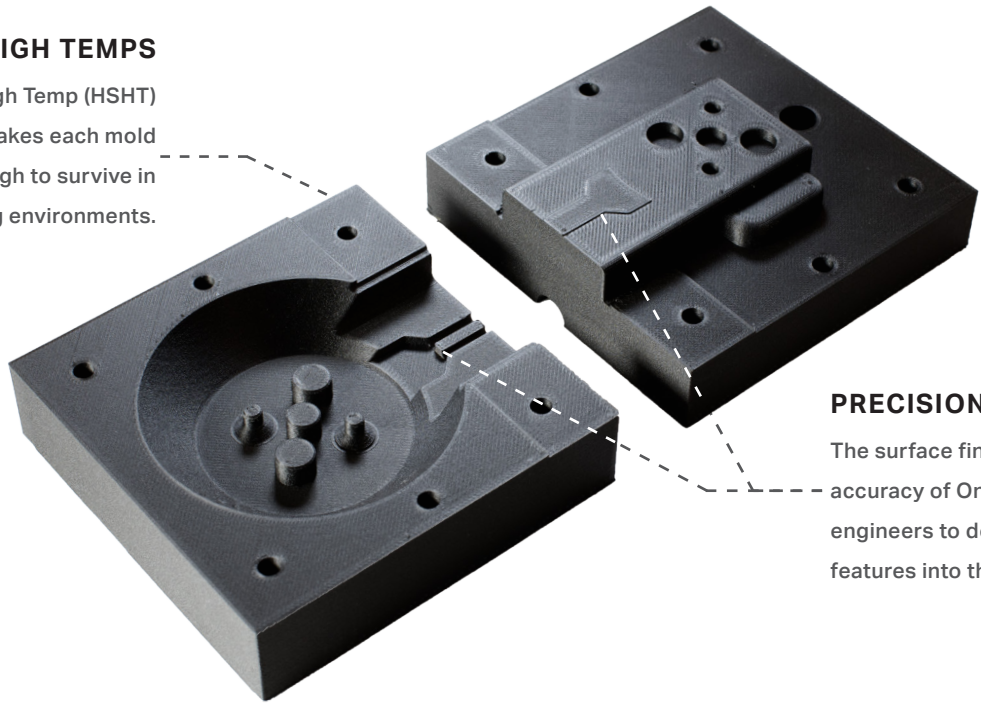
FAST LEAD TIMES — Onyx and HSHT printed molds replaced an inefficient, out-of-house silicone process.

MASSIVE SAVINGS — Humanetics prints molds **4x cheaper** and **2.5x faster** with Markforged technology.

The 3D Printed Part

ROBUST IN HIGH TEMPS

High Strength, High Temp (HSHT) fiberglass makes each mold piece robust enough to survive in thermoset molding environments.



PRECISION PRINTING

The surface finish and dimensional accuracy of Onyx allow Humanetics engineers to design precision features into their molds.

Next Day Molds

Molded thermoset plastics are widely used to take advantage of their strength and heat deflection temperatures. The quick turnaround time, low production cost, and long lifetime of Markforged printed molds make them an excellent fit for replacing traditional thermoset molding methods. Printed thermoset molds can withstand temperatures up to 302°F (150°C) for extended periods of time with minimal distortion.

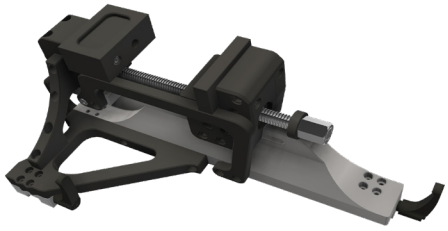
	SILICONE MACHINED	MARKFORGED	SAVINGS
Fabrication Time	144 hrs	60 hrs	58%
Fabrication Cost	$1,000	$240	76%

HUMANETICS® Innovative Solutions

Markforged

APPLICATION SPOTLIGHT

Tools and Fixtures



	Time	Cost
Traditional	3 weeks	$6,000
Markforged	1 week	$1,500
Savings	**66%**	**75%**

Lean Machine CNC is a metal fabrication shop in Saskatoon, Canada, working primarily for the commercial transportation and mining sector.

Challenge

Engineers needed to mill cantilevered workpieces, which meant that they had to control media removal.

Solution

The team used its Mark Two to create a low-profile custom vise and soft jaw combination.

Results

Complex workpieces, such as the cantilevered steel, can be accurately mill without wasting any material.

3D Printed Vise and Soft Jaws

Lean Machine is a metal fabrication job shop in Saskatoon, Saskatchewan, specializing in custom machining with a 5-axis CNC mill. A job for a customer required Kurt vises to hold a component while the mill cut the part. To avoid collision between the mill head and the vise, the stock would have to be clamped 12-14 inches from the cutting area. This was not an acceptable option, as a cantilevered part takes longer to machine and results in a less accurate cut. The team considered building their own metal custom vise, however they could not justify the $6,000 price tag.

The addition of a Markforged Mark Two led Lean Machine R&D Engineer Josh Grasby to use 3D printed components to build a cost-effective, custom vise/soft jaw combination. Comprised of over two dozen 3D printed continuous carbon fiber reinforced components combined with off-the-shelf parts, Lean Machine's custom printed vise can clamp 1.5 inches from the end of the extrusion, as opposed to 12-14 inches. The company has since taken on more complex jobs, all while applying a design for additive manufacturing approach to solving other problems they come across.

+ Non-Marring Material

Continuous carbon fiber holds up against cutting fluids and abrasive environments, making it the perfect material for machine shops.

+ Accurate Parts

Markforged's cloud-connected software ensures your parts are printed accurately, leaving no room for guesswork.

+ Speedy Process

Markforged 3D printers provide users with parts in a fraction of the time it takes for traditional processes.

MARKFORGED APPLICATION SPOTLIGHT

STANCHION ADAPTER

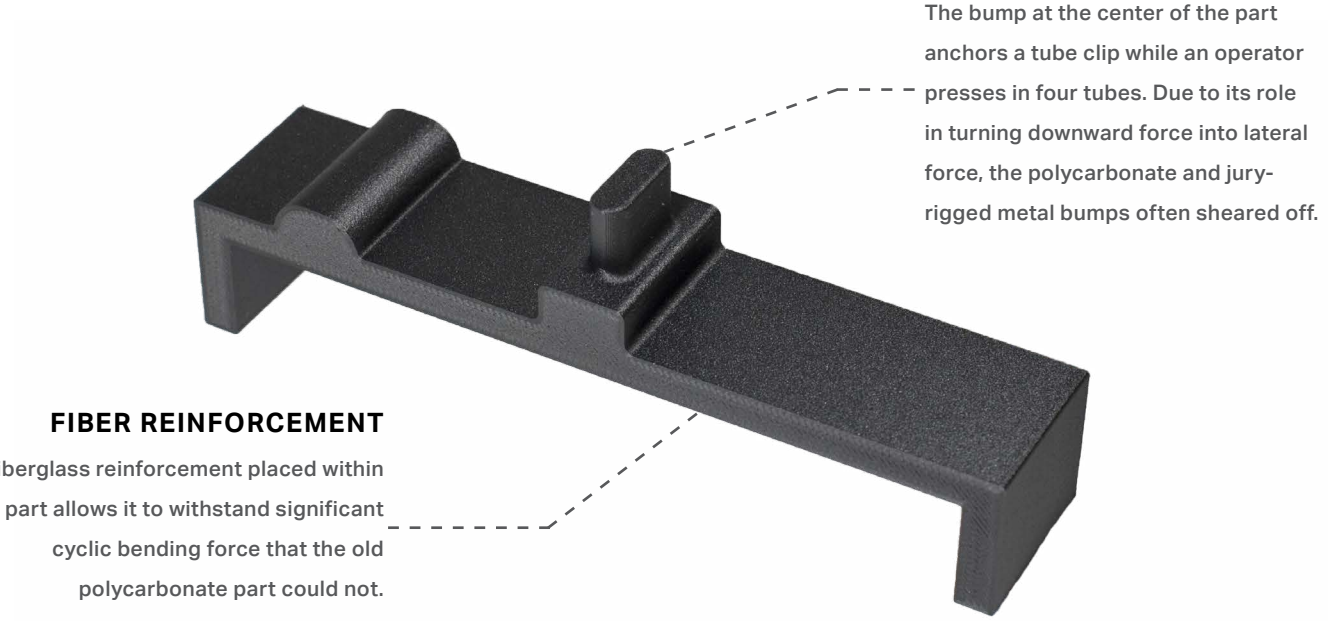
MANUFACTURING TOOLING — Eaton fabricates assembly line tooling to press tubes into hard plastic clips.

HIGHLY DURABLE — The stanchion adapter must securely constrain clips through repeated cyclic loading.

SUPERIOR MATERIAL — The Markforged part is stronger and faster to make than a polycarbonate version.

MASSIVE SAVINGS — Eaton now prints adapters **4x cheaper** and **41x faster** with Markforged technology.

The 3D Printed Part



STRONG LOCATING FEATURE

The bump at the center of the part anchors a tube clip while an operator presses in four tubes. Due to its role in turning downward force into lateral force, the polycarbonate and jury-rigged metal bumps often sheared off.

FIBER REINFORCEMENT

Fiberglass reinforcement placed within the part allows it to withstand significant cyclic bending force that the old polycarbonate part could not.

Assembly Line Tooling

Before using Markforged, Eaton tried several fabrication methods for their adapter. None yielded a part robust enough to survive on the factory floor. Their jury-rigged, welded adapter fell apart and their machined polycarbonate adapter broke with cyclic loading. Using a Markforged 3D printer, Eaton quickly printed a composite stanchion adapter. Comprised of chopped carbon fiber nylon material reinforced with Fiberglass, the part outperformed their previous iterations for far less cost than machined aluminum.

	CNC MACHINED	MARKFORGED	SAVINGS
Fabrication Time	3 weeks	12 hours	97%
Fabrication Cost	$115	$28	76%

Powering Business Worldwide

MARKFORGED.COM

MARKFORGED APPLICATION SPOTLIGHT

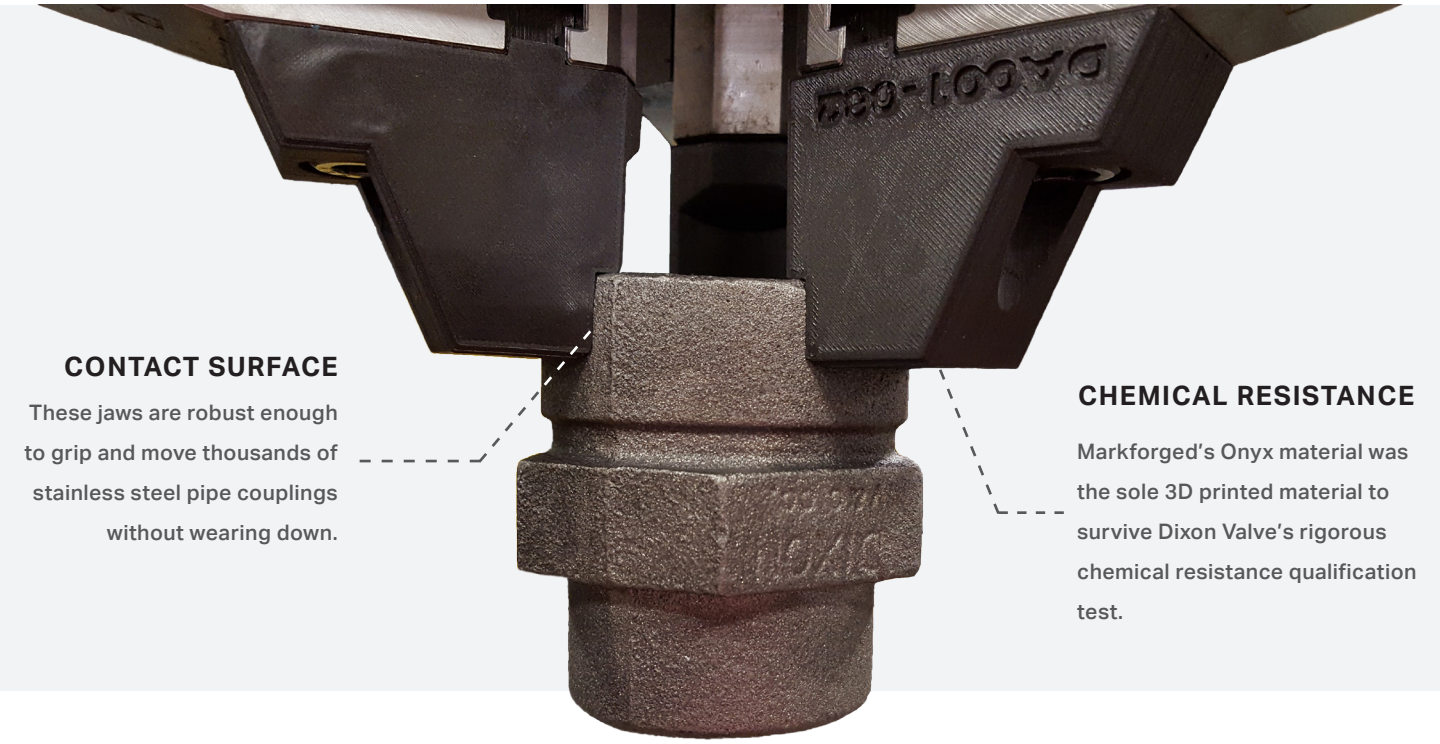
COMPOSITE JAWS

END OF ARM TOOLING — These jaws mount on a robot that transfers fittings between machining centers.

CHEMICALLY RESISTANT — Jaws must survive corrosive fluids while subjected to repeated clamping.

NEXT DAY TOOLS — With a Markforged Mark Two, Dixon Valve is able to retool a robotic arm in 24 hours.

MASSIVE SAVINGS — Dixon Valve achieved **30x cost savings** and **14x time savings** by printing these jaws.



CONTACT SURFACE

These jaws are robust enough to grip and move thousands of stainless steel pipe couplings without wearing down.

CHEMICAL RESISTANCE

Markforged's Onyx material was the sole 3D printed material to survive Dixon Valve's rigorous chemical resistance qualification test.

A New Paradigm

Markforged enabled Dixon Valve to produce new manufacturing tooling solutions faster and cheaper than ever before. System Engineer J.R. Everett describes the Markforged machines as "a critical component in our design process [that's] really changing the way we work to the point where we are actually altering our procedures and plans to accommodate it." With their Markforged machines, Dixon Valve engineers eliminated the need to outsource or machine in house the vast majority of their grippers.

	MACHINED	MARKFORGED	SAVINGS
Fabrication Time	144 hrs	9 hrs	93%
Fabrication Cost	$290	$9	97%