Desktop Metal™

[E-BOOK]

Fiber™

Continuous Fiber 3D Printing: Technology and Applications

www.desktopmetal.com

01 Print Aerospace-Grade Composites From Your Desktop

It's a term that's used a great deal in modern manufacturing, but what are composites?

Fundamentally speaking, a composite is a combination of two or more materials that forms a new material - one with properties that are superior to the individual components.

In the natural world, such materials are abundant - wood, bamboo, abalone, and even teeth and bone are all composites that evolved over billions of years to fit a particular niche.

When it comes to manufacturing, though, the term more often refers to a combination of plastic or epoxy resin and reinforcing fibers - think fiberglass or carbon fiber - that produces incredibly strong, stiff and lightweight parts.

Despite those benefits, the high price of most composites has significantly limited their use.

But those days may be coming to an end.

Enabled by 3D printing technology, it's now cheaper and easier than ever before for designers and engineers to create chopped fiber reinforced parts from tough, industrial-grade thermoplastics.

And for the most challenging applications, parts can be printed with continuous carbon fiber reinforcement, resulting in parts that can be stronger than steel, yet lighter than aluminum.

But additive technology brings more to composite manufacturing than just the ability to quickly and inexpensively create high-performance parts.

Because it's not bound by the geometric limitations of traditional manufacturing, 3D printing makes it possible to create more complex components. Printing parts also opens the door to consolidating a number of parts into fewer, multi-functional assemblies, resulting in simplified manufacturing, lighter parts and reduced waste.

That geometric freedom enables the use of generative design tools to create fully optimized parts with shapes that are inspired by nature and as much as 50 percent lighter than conventional designs.

02 Current Composite Manufacture

For decades, composite parts have been fabricated using the same labor-intensive and time-consuming hand layup process that makes mass production highly inefficient.

In addition to the need for expensive up-front tooling in the form of molds used to shape parts, the process - as the name suggests - is done almost entirely by hand, with technicians manually cutting material to size and pressing it into molds.

To ensure layers bind properly, parts are sealed in vacuum bags every few (typically 4-6) layers and compressed in an oven or autoclave, further slowing the process. Once all the layers are assembled, parts must cure in an oven or autoclave to set the epoxy before finally being removed from the mold and trimmed to their final shape.

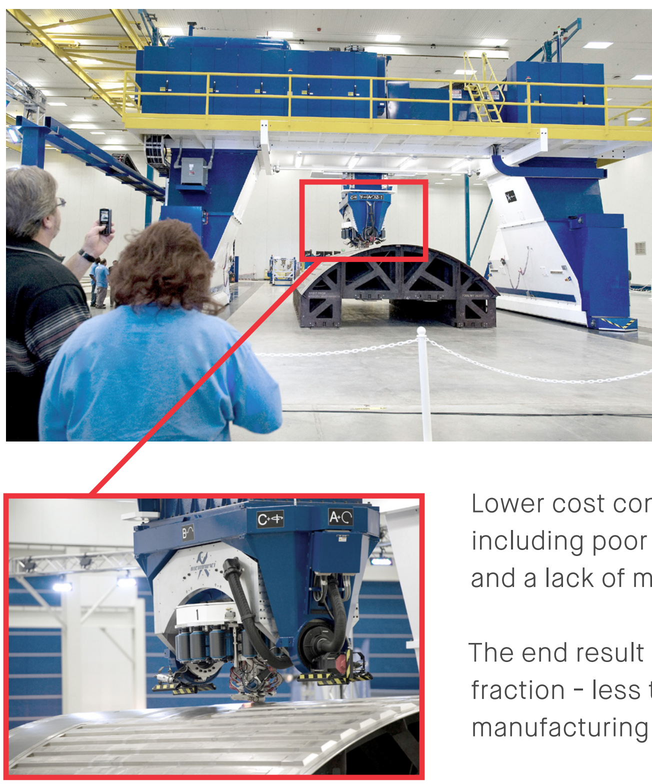
All told, the process can result in parts that cost more than $1,000 per pound - far too expensive for widespread use, particularly for smaller parts.

03 Enter Additive Manufacturing

To bring down those costs, manufacturers in recent years have turned to additive technology - with mixed results.

By far the most successful approach to 3D printing composite parts is a process known as Automated Fiber Placement (AFP), which relies on a robotic arm or gantry to lay resin-impregnated carbon fiber strands (typically referred to as tows) on molds or mandrels to build parts layer by layer.

The systems are most often used to form large parts, like airplane wings, wind turbine blades and - most famously - the fuselage of the Boeing 787 Dreamliner.



Though faster than hand layup, AFP systems are also extremely expensive - often costing several million dollars - and require specialized facilities to operate effectively.

Other systems have taken different approaches to 3D printing composites.

One has been to print parts using only chopped fiber, but the parts they produce tend to have poor mechanical properties, and the cost of the systems - $100,000 or more - can be hard to justify.

Lower cost continuous fiber printers, meanwhile, face similar problems, including poor part performance due to low fiber volume, high porosity and a lack of materials variety.

The end result is that 3D printing today accounts for just a tiny fraction - less than one tenth of one percent - of the entire composite manufacturing market.

04 The Desktop Metal™ Solution: Fiber™

With the introduction of Fiber™, Desktop Metal wants to make those challenges a thing of the past, and make composite manufacturing accessible to all designers and engineers.

To do it, Fiber™ marries two 3D printing technologies via a unique, tool-changing platform that utilizes two different print heads.

The first is an FFF head that prints chopped fiber reinforced filaments. The second - essentially a miniaturized version of the larger AFP systems - lays down continuous carbon fiber or fiberglass tape along critical load paths in a process dubbed Micro Automated Fiber Placement (μAFP.)

To create composite parts, Fiber™ swaps between the two, starting with the FFF head, which creates a part's 3D features.

In specific areas - defined either by the printer's software or by the user - the μAFP head takes over, laying down layers of reinforcing tape, which are then overmolded by the FFF head.

The end result is a part with an exceptional surface finish that can be as strong as steel yet as light as aluminum.

Designed to be an easy-to-use, end-to-end solution for printing composite parts, the system is completely automatic - users simply design their parts, identify areas for reinforcement, or allow software to optimize the reinforcement, and the system does the rest.

About Fiber™

Combining the strength of continuous fiber with the ease of FFF printing, Fiber™ can create parts that are as strong as steel yet as light as aluminum, and can stand up to the toughest environments.

Designed for versatility, with a range of materials, from high-temperature thermoplastics like PEEK and PEKK to PA6 nylon, Fiber™ is an easy-to-use platform - in a matter of minutes, users can be up and running, printing industrial-grade composites.

05 Materials

One of the key benefits of Fiber™ is its ability to print using a wide range of materials - particularly high-temperature thermoplastics like PEEK and PEKK. Though widely used in the manufacture of aerostructures, the two plastics are notoriously challenging to 3D print.

The Fiber™ platform makes it possible through a combination of material and process engineering, which ultimately enables users to print end-use parts for any number of industries, and for applications that range from research and development to assembly fixtures.

■ PEEK + Carbon Fiber

An industry-tested thermoplastic, PEEK has exceptional mechanical properties and high resistance to surface abrasions. Inherently flame retardant, the material can withstand continuous-use temperatures of up to 250 °C. When combined with continuous carbon fiber, the resulting parts are strong, stiff, and boast a high fatigue level—making this an ideal material for high-wear applications.

■ PEKK + Carbon Fiber

An industrial-grade thermoplastic known for both high tensile and compressive strength, PEKK is also resistant to chemical abrasions and can withstand continuous temperatures above 250 °C and is also ESD compliant. Parts reinforced with continuous carbon fiber are highly durable, making them sell suited for the most extreme environments.

■ PA6 + Carbon Fiber

When reinforced with continuous carbon fiber, PA6 Nylon has a tensile strength 30 times that of ABS, as well as a superior surface finish. With the ability to withstand temperatures up to 100 °C, PA6 with carbon fiber reinforcement is an excellent material for manufacturing jigs, fixtures and other applications that might otherwise require precision machined aluminum.

■ PA6 + Fiberglass

A low-cost material which renders lightweight, high-strength and corrosion-resistant parts, fiberglass-reinforced nylon is a great match for sporting goods applications where parts are exposed to the elements and have a low target cost per part.

06 Applications

With a diverse set of materials, easy-to-use platform and affordable price, Fiber™ is an ideal solution for composite manufacturing across a host of markets - from small composite manufacturers to large-scale industry research and development.

Small Composite Manufacturing Shops

Machine Shops

Industry R&D and Manufacturering Operations

University and Education

06 — Applications

Small Composite Manufacturing Shops

For small composite manufacturers who still rely on the slow, laborious process of hand layup, Fiber™ translates into lower lead times and faster turnaround as well as the ability to produce more complex - and more affordable - parts.

Among the ways small shops can use the Fiber™ platform:

—

Mold Tools

Traditional mold tools are heavy, expensive to make, require long lead time and exhibit high thermal expansion. Composite tools, however, can dramatically reduce tooling costs and show little thermal expansion.

—

Assembly Fixtures

Traditional fixtures require long lead times and are expensive to produce. Custom, 3D printed fixtures can be quickly produced to assemble components at less cost.

—

End-use Parts

Composites are ideal materials for items like sporting goods - bicycle components, tennis racquets and golf clubs, as well as covers, structural beams and plates, brackets, clips, fins and blades and dozens of other end-use parts.

—

Prototypes

By enabling rapid iteration on prototypes, engineers can test multiple designs before finalizing a part design and investing in tooling.

06 — Applications: Small Composite Manufacturing Shops

Material:
PA6 + Fiber Glass

[Part Example 01]

Sky Diving Camera Mount

Used to attach a camera to a skydiving helmet, this mount must be extremely strong and stiff to support the weight of the camera and resist the forces that occur while freefalling at 100 miles per hour. Using Fiber™, manufacturers can print this mount overnight.

FFF Material:
PA6 + Fiber Glass

Taep Material:
PA6 + Fiber Glass

[Part Example 02]

Surfboard Fin

With design considerations that include the fin's rake, cant, base length, height and more, creating functional prototyping of these parts - versus the hand layup process used today - is desirable and composites are ideal for this part due to their high strength. In this case, the part is made from PA6 nylon with fiberglass reinforcement to keep costs low and to resist corrosion.

FFF Material:
PA6 + Carbon Fiber

Tape Material:
PA6 + Carbon Fiber

[Part Example 03]

Ski Binding Heel Track

The ski binding heel track attaches to the base plate on a ski, allowing the heel binding to be adjusted. To withstand the forces experienced by the ski as it turns, this part needs to be extremely stiff, making composites an ideal choice. Using Fiber™, manufacturers can prototype this part before it is mass produced via injection molding.

06 — Applications

Machine Shops

Using Fiber™, machine shops can quickly create tools and fixtures with custom geometry that conforms to complex parts and is strong enough to hold parts steady during secondary machining operations - saving both time and money.

Among the ways machine shops can use the Fiber™ platform:

—

Soft Jaws

To hold or grip objects during machining, soft jaws often require custom geometry and must be strong enough to hold parts steady. Printing custom composite tools can help manufacturers save time and money, and lighter weight can save wear-and-tear on machinery.

—

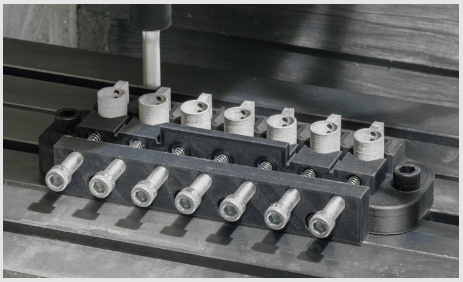
Machining Fixtures

Used to securely locate and support workpieces during machining operations, fixtures can be custom-printed for each part.

06 — Applications: Machine Shops

FFF Material:
PA6 + Carbon Fiber

Taep Material:
PA6 + Carbon Fiber

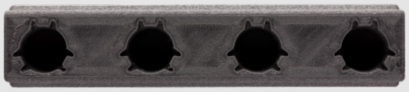


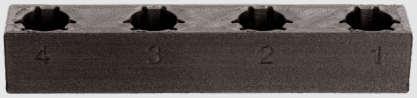
[Part Example 01]

Lock Barrel Machining Fixture

Designed to hold lock barrels in place during a secondary reaming, this part must be very stiff to tolerate the forces and vibration of the reaming tool. The rapid turnaround of Fiber™ means this part can be produced overnight, while the toughness of composites result in a part with material properties similar to aluminum.

FFF Material:
PA6 + Carbon Fiber





[Part Example 02]

Shroud Holder

Designed to hold metal injection molded shrouds in place as an articulated robot picks them up and places them in a CNC fixture, this part features customized geometry that conforms to the shrouds' shape. Due to their stiffness and wear resistance, composites are ideal for this part.

FFF Material:
PA6 + Carbon Fiber

[Part Example 03]

Assembly Fixture

Used to hold sheet metal housings while fasteners and electronics are installed, this fixture can help increase assembly speed and consistency. This part was created using PA6 nylon with carbon fiber reinforcement for its stiffness and wear resistance.

06 — Applications

Industry R&D and Manufacturing Operations

For industry, Fiber™ is an ideal tool for both research and development and manufacturing, allowing companies to quickly and inexpensively iterate on new designs across a host of products, and to create custom components tailored to specific applications.

Among the industry applications for the Fiber™ platform:

—

Robotic End Effectors

Custom designed small, flexible robots with limited payload capacity, end effectors must be lightweight, but stiff and strong enough to carry loads. If a particular application involves handling circuit boards, the devices must also be ESD-compliant.

—

Drones/Rockets/Cubesats, etc

For small aerospace structures where weight is critical to performance, Fiber™ can help companies iterate on designs and create functional prototypes of a wide array of components.

06 — Applications: Machine Shops

FFF Material:
PEKK + Carbon Fiber

Tape Material:
PEKK + Carbon Fiber

[Part Example 01]

UHF Radio Housing

An ultra high frequency radio housing for use in a cubesat, the complex geometry and small features of this part make it ideal for printing. Due to the extreme temperatures this part will face in spacex, this part was printed using PEKK.

FFF Material:
PEKK + Carbon Fiber

Tape Material:
PEKK + Carbon Fiber

[Part Example 02]

Rocket Fin

Fins are critical to keep a rocket stable in flight, but must be custom designed for each rocket to ensure optimal flight. Rather than simulate how fins will perform, 3D printing enables designers to create functional prototypes and iterate on geometry based on testing. With its high specific strength and temperature resistance, carbon fiber reinforced PEKK is an ideal choice of material.

Material:
PEKK + Carbon Fiber

[Part Example 03]

Brake Duct

This duct was custom-built for a BMW race car that will compete in the Pikes Peak Hill Climb, and is designed to move air from the front of the car to cool the brakes. The complex shape of this duct can only be made using additive technology, and using composites helps reduce the car's weight, leading to faster race time. Because brakes can generate heat in excess of 200 °C, PEKK was selected for this part due to its high heat-resistance.

06 — Applications

University and Education

Educational institutions play a key role in training the next generation of designers and engineers, but the high cost of many composite 3D printing systems mean few colleges or universities can afford to invest in them, and students rarely have a chance to get hands-on experience.

The dramatically lower price of Fiber™, however, enables colleges and universities to potentially invest in multiple systems, ensuring students have the chance to design, build and test real parts and to build the skills they will need as they enter the workforce.

Among the educational applications of Fiber™ platform:

—

Prototyping

Because it enables rapid iteration on prototypes, students can quickly build and iterate on designs to optimize functional assemblies for their own projects.

—

Skills Training

As 3D printing increasingly becomes part of the manufacturing landscape, students entering the workforce will need to have skills using the technology. The Fiber™ platform is a useful teaching tool for both additive and composite manufacturing.

06 — Applications: Industry R&D and Manufacturing Operations

Material:
PEKK + Carbon Fiber

[Part Example 01]

Motor Housing

This part holds a motor in a Battlebot featured on a Discovery Channel program. On the show, teams must work on extremely tight schedules to design and manufacture their robot, so the speed of 3D printing is a significant benefit. By printing this housing, the team was able to have the part in hand in just hours, allowing them to quickly iterate on the design. Since flamethrowers are allowed in the contest, carbon fiber-reinforced PEEK was chosen for this part due to its ability to withstand high heat.

Material:
PEKK + Carbon Fiber

[Part Example 02]

Balance Shaft Gear

Used to reduce vibration in rotary components, balance shaft gears are typically made from machined steel for strength and heat resistance, or injection-molded PEEK to reduce weight. Printing this part allowed students to quickly iterate on and test the design under real-world conditions. Carbon fiber-reinforced PEEK was chosen for this part to maintain strength and light-weighting, while also reducing lead time to hours and cutting manufacturing costs to just $54.

Material:
PEEK + Carbon Fiber

[Part Example 03]

Rocket Tail Cone

Added at the base of a rocket to ensure optimal airflow and reduce drag, this tailcone features complex geometry that could only be 3D printed. Because it eliminates many of the constraints of traditional manufacturing, printing this part allowed students to quickly produce prototype parts and iterate on the design, resulting in an optimized part that allows the rocket to fly higher and faster. Chopped fiber-reinforced PEEK was chosen for this part due to its high specific strength, temperature resistance and low thermal expansion.

Appendix.A

MATERIAL PERFORMANCE

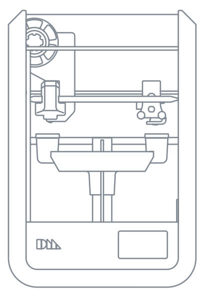
	FFF Chopped Fiber Filaments				µAFP Continuous Fiber Tapes				Reference		
Material Composition	PA6 + Carbon	PA6 + Glass	PEEK + Carbon	PEKK + Carbon	PA6 + Carbon	PA6 + Glass	PEEK + Carbon	PEKK + Carbon	ABS	Aluminum (6061)	Steel (4140)
Tensile Modulus (GPa)	3.8	4.2	8.1	7.9	117	30	145	139	2.3	70	200
Tensile Strength (MPa)	63	63	105	110	1416	900	2400	2300	39	310	655
Tensile Strain at Break (%)	3	6	3	3	1.3	2.4	0.8	0.8	24	17	25
Flexural Modulus (GPa)	3.7	3.6	8.3	8.1	71	29	124	124	2.4	70	200
Flexural Strength (MPa)	84	72	136	129	660	750	2000	2000	74	310	655
Density (g/cm3)	1.17	1.35	1.39	1.38	1.73	1.45	1.57	1.57	1.06	2.70	7.85

Appendix.B

Fiber™ Model Comparison:

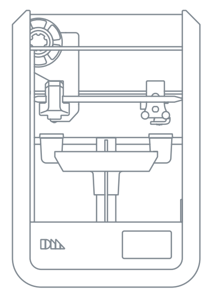
Fiber™ LT

Print high-strength, ESD-safe, nylon-based continuous fiber parts with exceptional mechanical properties.



Fiber™ HT

Print industrial grade, chemical-resistant, flame-retardant, and ESD-safe parts with PEEK-, PEKK-, and nylon-based continuous fiber materials.



	Fiber™ LT	Fiber™ HT
Price	Starting at $3,495/yr	Starting at $5,495/yr
Build Size	310 x 240 x 270 mm	310 x 240 x 270 mm
Layer Height	50 µm	50 µm
Compatible Materials	PA6 + CF PA6 + FG	PEEK + CF PEKK + CF PA6 + CF PA6 + FG
Reinforcement	Automated optimization	Automated optimization Custom, targeted reinforcment

About Desktop Metal

Desktop Metal, Inc. is accelerating the transformation of manufacturing with end-to-end metal 3D printing solutions.

Founded in 2015 by leaders in advanced manufacturing, metallurgy, and robotics, the company is addressing the unmet challenges of speed, cost, and quality to make metal 3D printing an essential tool for engineers and manufacturers around the world.

In 2017, the company was selected as one of the world's 30 most promising Technology Pioneers by the World Economic Forum, and was recently named to MIT Technology Review's list of 50 Smartest Companies. For more information, visit www.desktopmetal.com.