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HIGH-TEMPERATURE SOLUBLE CORE

Applications in Additive Manufacturing

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Soluble cores are easily removable tooling used to fabricate complex composite structures such as carbon fiber and glass fiber-reinforced polymers. The fiber is wetted with a thermosetting resin and then laid up on the outside of these internal temporary sacrificial cores in order to hold their shape while they cure or solidify under heated and, usually, pressurized conditions. After the resin-fiber composite has cured, the core is dissolved away, leaving behind only the hollow composite.

Terminology Key

Soluble core - internal tooling designed to be disintegrated and removed after composite fabrication.

Hollow composite manufacturing - creation of hollow core materials.

Carbon fiber lamination - process in hollow composite manufacturing where carbon fiber is wrapped around material and cured.

3D printing elevates this process by accommodating complex designs with support structures in places that are normally unreachable that can now be removed mechanically compared to traditional methods. However, conventional printable materials suffer from high materials costs and the limited ability to withstand the high temperatures and pressures during the carbon fiber lamination used in high performance composite manufacturing.

Infinite Material Solution's water-soluble support material AquaSys® 180 addresses these concerns, saves process time and money, and creates new opportunities for innovation. In this whitepaper, AquaSys 180's particular specifications create exciting potential in industries and applications with high engineering-performance demands.

This whitepaper also explores the current market of soluble core solutions, the nuances behind their limitations, and a case study with real results that utilizes AquaSys 180-printed soluble cores to create a carbon fiber wing for a customer in the aerospace industry.

HOLLOW COMPOSITE MANUFACTURING APPLICATIONS

Traditional Methods

Manufacturing hollow composites requires internal removable tooling to support the fiber fabric before it has cured. Soluble cores are single-use internal tooling that are dissolved or destroyed at the end of composite part production.

Traditionally, manufacturers have used tooling such as rigid inserts or inflatable cores for hollow composite manufacturing, but these methods have significant drawbacks:

Rigid Inserts are typically made of metals, composites, or polymers and provide a rigid surface that shape the inside of the composite structure.

Inflatable Cores (or Bladder Tooling) involve an elastomeric core that inflates during curing to expand and compress the composite against outside rigid tooling.

Utilizing non-soluble cores can be expensive, labor-intensive, and restrictive. Reusable tooling is typically machined, which is an expensive process often requiring substantial lead time. Additionally, the tool surfaces may require significant clean-up and prep work in between uses. Multi-part cores leave ridges and seams in the final composite part, complex cores often cannot be created, and the process could be unsuitable for low to medium-volume production.

Soluble cores such as eutectic salt cores and plaster-based cores can be used to replace other forms of internal tooling. These rigid structures are designed to be disintegrated and are removed after composite fabrication. These cores help create complex cavities and make removing internal supports easier in composite parts manufacturing. Salt or solid-plaster cores achieve high tolerances and water solubility avoids caustic solutions for core removal.

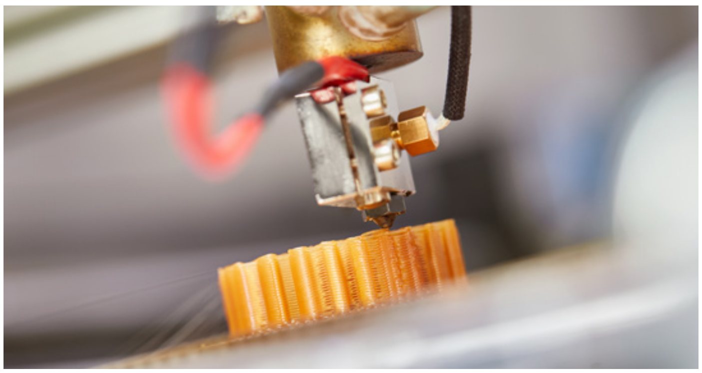
But there are drawbacks:

- Materials are expensive
- Washout and finishing is labor-intensive
- Cast-plaster has a lower dimensional accuracy
- Finished product can be very fragile to handle
- Processing issues when combined with liquid molding

3D Printing Methods

3D printing a soluble core through additive manufacturing technologies such as fused deposition modeling (FDM)/fused filament fabrication (FFF), stereolithography (SLA), and binder jetting helps alleviate some of these issues. In these processes, a soluble core is first 3D printed to match the geometry desired. The mold is then laminated with the carbon fiber and the assembly is cured at a high temperature and pressure to solidify the composite. Subsequently, the soluble core is dissolved, leaving only the carbon fiber-based structure.

These 3D printing processes can achieve high tolerances and dimensional control for soluble core compared with rigid inserts and inflatable cores. They can help in creating nearly fully enclosed composite parts and more complex geometries as removal of the core does not need such a large opening. Making a complex core in a single piece eliminates ridges and seams, preventing the potential weakness that comes from seams, and creates a smoother interior surface. Also, the process reduces lead times through elimination of additional tooling (i.e. rigid outer tooling).

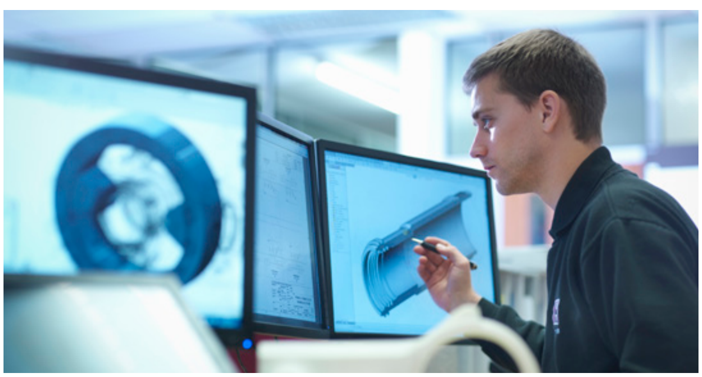


Low-volume composite part production

For low-volume composite part production, 3D printing has a lower cost of fabrication and lower materials cost. Additionally, the tooling can be produced on-demand to alleviate inventory concerns.

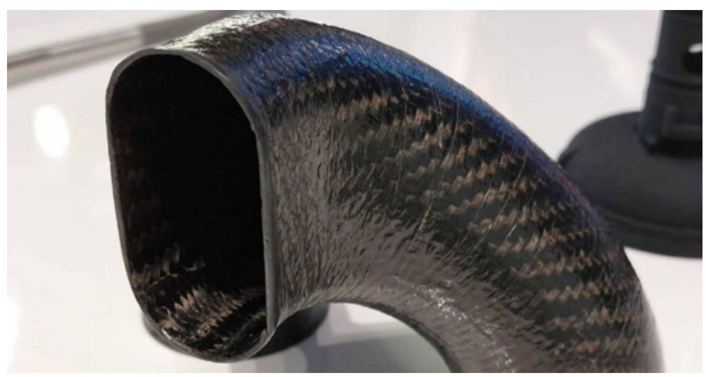
Washing out the core

The removal of core through washout is less likely to be labor-intensive. Because you simply wash away your core after the part is cured, you also eliminate the risk of damage during core extraction.



Design freedom

3D Printing allows the soluble cores to be designed in nearly any shape. The range of shapes possible through printing is much larger than those that can be machined through conventional processes. Additionally, each core produced could have a unique shape enabling applications where mass customization is a benefit.



Carbon fiber integrity

3D printing a soluble core when using a water-soluble support material creates a complex geometry quickly and dissolves the core without compromising the integrity of the carbon fiber lamination. When using a water-soluble 3D-printable core material, water is harmless to the final fiber composite and will not affect its properties.

3D Printing Technologies

3D printing a soluble core with the following technologies offers benefits in their ability to accommodate complex core designs, preserve carbon fiber integrity, and its ease of removal when compared to traditional methods. However, there are still disadvantages to these methods that prevent them from being widely used.

FDM / FFF

Fused Deposition Modeling (FDM) / Fused Filament Fabrication (FFF)

Advantages

- Most accessible technology from a price and usability standpoint
- Large-format printers are typically at a lower price point than SLA and binder jetting

Disadvantages

- Poor surface finish (need post-processing to remove build lines)
- Slow for large-format or higher volumes of prints
- Some designs may require support structures.
- Has higher chances of failure with high-build height prints (less helpful for larger geometries)

SLA

Stereolithography (SLA)

Advantages

- Prints parts with high surface finish
- Better suited for high-volume applications due to longer build times in FDM and binder jetting
- Best accuracy and part quality compared to FDM/FFF and binder jetting

Disadvantages

- Safety concerns when handling resin
- Resins typically more expensive than filaments or sand
- Parts may require support structures.
- Large-format SLA printers are rare and more expensive

BINDER JETTING

Binder jetting

Advantages

- Accommodates larger prints or higher volumes of prints in a faster build time (i.e. multiple nested prints on the same build plate)
- Sand, a major component, is cheaper than filaments or resins

Disadvantages

- Most expensive printer technology
- Requires coating of any sand part before use to prevent resin migration and increase surface finish
- Typically does not print detail or fine features well– unsuitable for smaller, detailed prints

for 3D Printed Soluble Core

Opening a world of possibilities with soluble core

3D-printed soluble cores are opening up opportunities across numerous industries and applications. Hollow composite parts with complex geometry and/or partial hollow geometry can be made in low or high-volume applications depending on the manufacturing method.

As materials, printers, and innovators continue to evolve, soluble cores will continue to thrive in applications where the best solution requires complex voids. If a production process features master molds, production fixtures, trim tools, or layup tools to manufacture composite parts, creating soluble cores using additive manufacturing can offer better part performance, as well as time and cost savings, benefits which far outweigh the cost of the material.

Aerospace

Aerospace is an opportunity for 3D-printed soluble cores if the 3D printing material is compatible with high performance composites and the curing temperatures and consolidation pressures they require for manufacturing.

Aerospace can utilize 3D-printed soluble cores in the fabrication of wings, doors, and other parts that could be optimized to reduce weight, which saves money. With soluble core applications, engineers have greater design freedom to conceive and print complex vents, ductwork, and carbon-fiber components for aircraft manufacturers.

Automotive

Automotive manufacturers are among the most prolific users of hollow composite parts, as cars look more to composites to decrease weight and increase cost savings. Ducts, pipes, and manifolds offer excellent use cases for 3D-printed soluble cores given the composites used in the industry.

Soluble-core use is a mature technique in automotive, where it can also create automotive chassis, car doors, and other components. 3D printing can replace inflatable bladders which are used to fabricate chassis components, in order to make them more lightweight.

Motorsports

While all cars benefit from lightweight parts, racing vehicles have uniquely demanding weight reduction needs. This is why the most common users of 3D-printed soluble core applications are in the industry of motorsports. Motorsports rely on complex ductwork (which soluble cores are an ideal solution for), manifolds, and pipes—whose low-volume, complex geometries, and turnaround requirements are well suited for techniques in this sector.

With light-weighting always a concern in the industry, 3D printing can displace inflatable bladders, which are often used to fabricate chassis components in motorsport. Also, an air intake manifold on a Formula 1 car can be optimized to meet the industry's time-sensitive needs.

Additional applications

More opportunities for expansion of 3D-printed soluble core applications exist in composite research and development (R&D), prototyping, and composite furniture. Additionally, there is potential for hollow composite parts in the following sectors:

- **Consumer and Sports Goods:** rackets, paddles, clubs, luxury goods, bicycles (i.e. frames and seats) and biking accessories (i.e. helmets), and furniture (i.e. luxury chairs)
- **Energy (Oil/Gas and Renewable):** wind turbine blades, ducts, buoys and gas turbine burners
- **Electronics:** lightweight enclosures and robotic components
- **Marine:** pressure vessels, hulls, and spars
- **Healthcare:** prosthetics
- **Satellites:** complex ducting

COMPETITIVE MATERIALS

for 3D Printed Soluble Core

Various technologies exist for 3D printing soluble core solutions.

Stratasys ST-130 (FDM/FFF)

A dissolvable filament made of polycarbonate and acrylonitrile butadiene styrene (ABS) that is specifically marketed towards soluble tooling applications (as opposed to Stratasys' SR-130, a polycarbonate dissolvable filament that is generally marketed).

Advantages

- Stratasys has highest brand recognition amongst 3D-printing soluble tooling competitors
- Stratasys has highest penetration in the market (based on known end-users)
- FDM is the most accessible/ cheapest 3D printing process

Disadvantages

- Requires using proprietary Stratasys printer (may change with Open License) and removal chemicals
- Removal solution degrades final composite part

Covestro Somos DMX-SL 100 (SLA)

A stereolithography resin specifically marketed towards soluble composite tooling, especially hollow composite tooling.

Advantages

- Does not require detergent solution for washout (which affects mechanical properties)
- SLA can achieve higher surface finish than FDM/binder jetting, which leads to better properties in the composite
- SLA better for higher volume production than FDM

Disadvantages

- Resins are much more expensive than filaments or sand
- SLA printers (especially large ones) will be 2-3x more expensive than FDM printers
- More safety concerns when printing with SLA than FDM
- Requires time-consuming post-processing after printing, including rinsing off residual resin and drying the printed parts

ExOne (binder jetting)

A service where ExOne prints soluble tools/cores through binder jetting for customers to use for composite manufacturing.

Advantages

- Customer doesn't need to invest in 3D printing equipment/ materials to use 3D-printed soluble cores
- Does not require detergent solution for washout (which affects mechanical properties)
- Binder jetting can make very large parts quicker than FDM or SLA
- Sand is generally a lower cost 3D printing material (especially compared to resin)

Disadvantages

- Customers have no ability to bring core production in-house (or would need to invest in ~$500K binder jetting printers and make their own coatings)
- Cannot make very detailed prints
- Ability to withstand high pressures is unclear

Utilizing AquaSys 180 for Soluble Core

The compatibility and material characteristics of AquaSys 180 make it ideal for soluble core applications. AquaSys 180 filament used in FFF printers is a preferrable method for creating soluble core solutions compared to other 3D printing materials and methods and traditional hollow composite lamination methods. Its benefits include reducing process time, saving money, allowing for high-temperature requirements, facilitating rapid customization for complex geometries, and containing a desirable pH for carbon fiber lamination.

Faster time-to-part and increased savings

Creating complex geometries in a traditional approach, such as creating two halves via clamshell molds in an autoclave and combining them into the finished part, is a time-consuming process that incurs a great deal of financial strain. An AquaSys 180 soluble core sidesteps those steps entirely.

Removing the core itself can often be cumbersome and labor-intensive through other methods. But AquaSys 180's fast water-only dissolution efficiently streamlines disposal.

AquaSys 180 helps produce soluble tooling solutions in a matter of days—not months.

With a more efficient process timeframe, considerable amounts of financial savings are also obtained (specifically if utilizing in-house printers).

High-temperature compatibility

Previously, the temperature and pressure requirements of the autoclave processes used in carbon composite part manufacturing ruled out the use of water-soluble support materials for soluble core use. Most support materials have temperature limits (250°F, 121°C) - above which they will deform under pressure - that effectively rule out their application as soluble cores.

AquaSys 180 expands the application envelope. AquaSys 180 can be printed at chamber temperatures up to 180°C and maintains structural integrity up to 150°C under typical autoclave pressures (7 bar).

Creating complex forms

AquaSys 180 for soluble core opens up new options for composite production forms. Soluble core hollow forms with complex geometry and overhangs can be created. With its rapid customization for complex geometries, AquaSys 180 soluble cores allow for tremendous innovative design freedom.

AquaSys 180 users now have access to design features such as internal threading, interior suspension, and moving components using water-soluble supports, which demonstrate how the support material performs for more demanding 3D-print applications.

Clean adhesion and carbon fiber integrity

AquaSys 180 and carbon composites form a strong adhesive bond, resulting in a smoother composite interior with no wrinkles.

The process also contains a desirable pH for carbon fiber lamination and doesn't compromise the integrity of the remaining carbon fiber after dissolution.

Putting AquaSys 180 soluble cores into practice

Creating a soluble core with AquaSys 180 enables quicker complex designs, expanded material compatibility, and a reduced time-to-part rate for users seeking the design freedom and flexibility of open printing systems—challenges no other material on the market is solving this broadly and effectively. This allows for efficiency and innovation across several industries and applications.

What sets AquaSys 180 apart from the competiton?

	AquaSys 180	Breakaway	PVA/BVOH	Chemical-soluble
Compatible with engineering-grade build materials	☑	☑	—	☑
Compatible with PEEK, PEKK, PEI, and PPSU	☑	☑	—	—
Requires minimal post-processing	☑	—	☑	☑
Enables safe, simple disposal	☑	—	☑	—
Stable at high temperatures	☑	☑	—	—
Dissolves in just tap water*	☑	—	☑	—
Supports complex geometries	☑	—	☑	☑

*AquaSys 120 is 100% soluble, while AquaSys 180 contains approximately 20 wt% of an inert, non-hazardous, non-biodegradable component that should be collected and disposed of after dissolution.

CASE STUDY

Creating a Prototype Wing in Two Weeks

A customer in the aerospace industry requested a complete hollow carbon-fiber wing. Controllo Qualità, a service bureau that fulfills 3D printing requests in-house and Infinite's AquaSys distributor in Italy, took up the request. The wing needed to be completed and shipped to the customer within two weeks – an unusually short turnaround time for a job this involved. As a result, there would only be one chance to create the parts, with not much opportunity for trial and error.

A fundamental problem occurs when temperature and pressure increase in tandem in the composite curing process. If pressure is applied to a lower performing material, the material starts to collapse or buckle. The goal is to reach 180°F (the maximum for that carbon fiber composite), but to have a balance between pressure and temperature.

Process

- **Design:** Through desktop research, the Controllo Qualità team identified a publicly available STP file that nearly matched the customer's wing request. Then they made minor adjustments to maximize dimensions. This shortened the design phase of the process, which can require creating a new geometry from scratch.
- **Printing:** They printed 295mm-high airfoil shells using AquaSys 180 filament in a large-format FFF machine, making sure to deposit extra-thick layers near the walls to account for high pressure during the curing process. Printing took roughly 30 hours from start to finish.
- **Lamination:** They applied polyethylene terephthalate (PET) heat-transfer tape to the outside of the printed molds — helping to alleviate surface issues common among parts made using FFF — and applied the pre-preg carbon fiber fabric.
- **Curing:** The molds were cured out of autoclave at 130°C.
- **Dissolution:** Finally, the carbon fiber pieces were placed in a dissolution bath of water heated to 120°C. The AquaSys 180 molds dissolved over several hours, leaving behind hollow composite wing parts to be shipped back to the customer and assembled.

Results

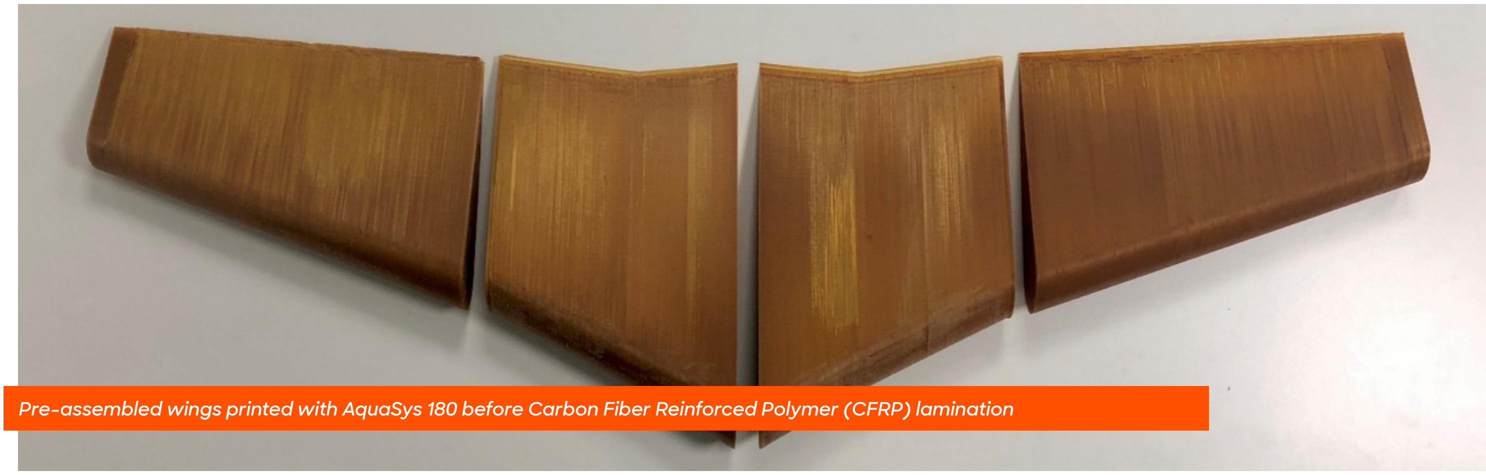
The quality of the finished wing exceeded the customer's expectations, and it was delivered on schedule. Because Controllo Qualità used 3D-printed soluble cores instead of traditional methods like bladders or rigid inserts, they were able to create a complex design quickly that could be easily removed. And because they used AquaSys 180 instead of other soluble materials that require solvent baths, the integrity of the remaining carbon fiber was not compromised after dissolution.

> "We've seen the results and the results are clear: AquaSys 180 is now the golden standard for soluble core solutions."
>
> Flavio Tarsitano, Technical & Sales Manager, Additive Manufacturing Specialist

Technical Consideration for Utilizing AquaSys 180 in Soluble Core

Carbon fiber temperature limits

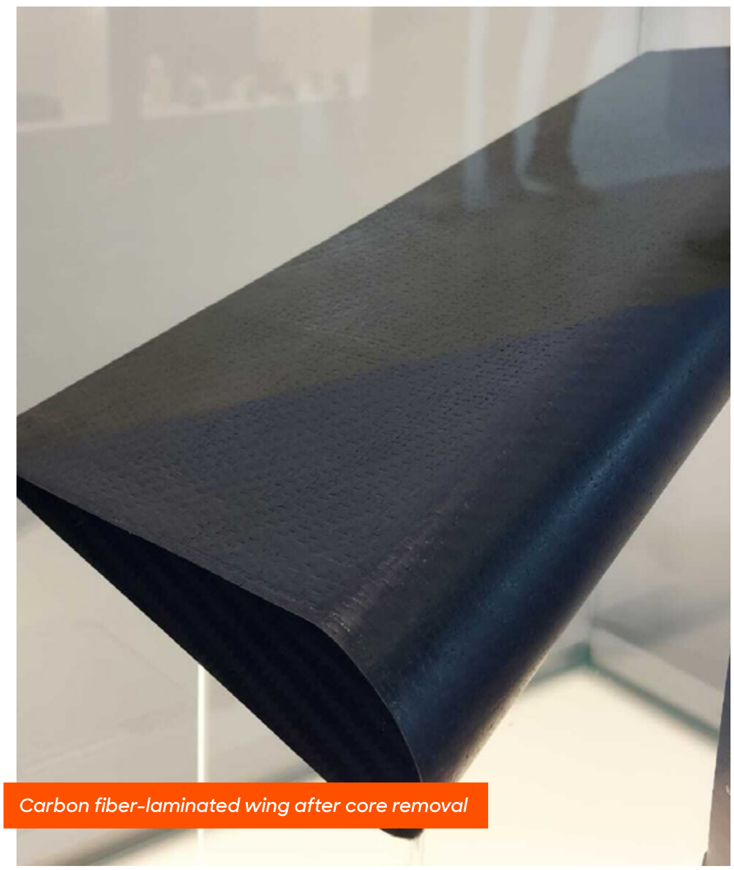
AquaSys 180 allows for high-temperature carbon fiber composite fabrication, but there is even more potential possible at higher temperatures. Infinite Material Solutions will be releasing new grades of AquaSys in the future to solve for these higher temperatures in order to unlock new applications.



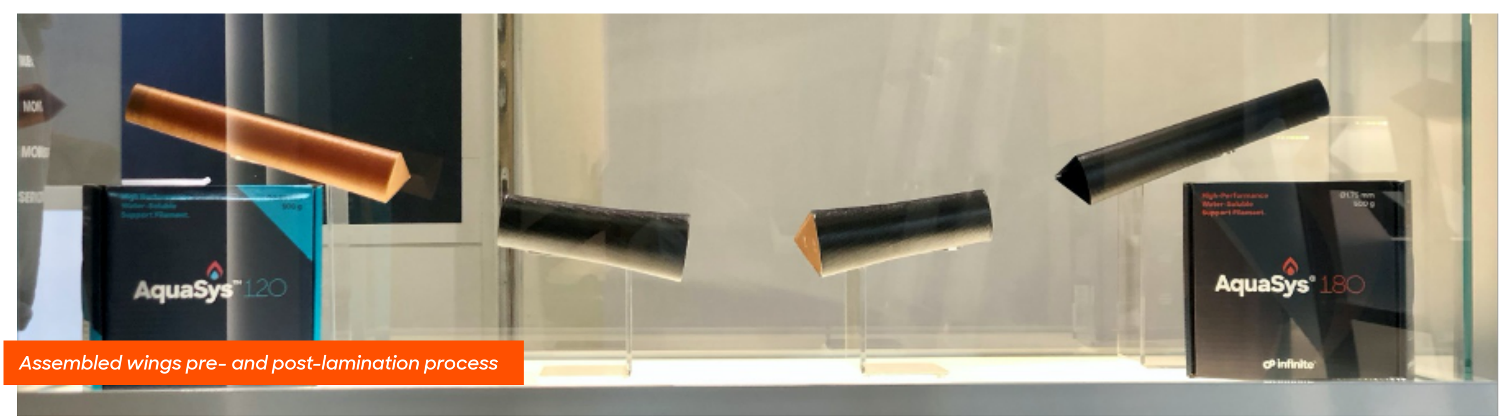
Pre-assembled wings printed with AquaSys 180 before Carbon Fiber Reinforced Polymer (CFRP) lamination

Left wing finished but not laminated

Carbon fiber-laminated wing on AquaSys 180 core



Carbon fiber-laminated wing after core removal



Assembled wings pre- and post-lamination process

Notes

Left wing during cooldown inside printer

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Work with Us on Your Next Hollow Composite Project

We love printing the future. Let's discuss the soluble core solution you need for your additive challenges and how we can work with you to test your application with an AquaSys 180 sample. Send us a digital file of your geometry and let's get the conversation started.

Talk to one of our experts about how AquaSys 180 can work for your applications:

Contact us at **info@infinitematerialsolutions.com**

Or visit **infinitematerialsolutions.com** to learn more.

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