



# FDM Sacrificial Tooling for Composite Part Fabrication

**USING ADDITIVE MANUFACTURING FOR SACRIFICIAL COMPOSITE TOOL PRODUCTION**

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By Ross Jones, Stratasys Composite Tooling Team

Additive manufacturing (AM), or 3D printing as it is more commonly known, has seen an explosion of material options in recent years. With these new material options comes significant improvements in mechanical properties and the potential for new applications that extend well beyond prototyping.

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Adopters of Stratasys 3D printing solutions are utilizing its unique benefits to reduce costs, greatly cut lead times, and improve ergonomics and functionality for composite lay-up tooling and related tooling such as drill guides, trim tools, machining fixtures, and countless other manufacturing aids.

### FDM SACRIFICIAL TOOLING – APPLICATION OVERVIEW

For composite manufacturers, additive manufacturing can fundamentally change the procedure for creating complex, hollow composite parts.

Traditional composite manufacturing techniques work well to produce basic shapes with constant cross sections. However, complex composite parts with hollow interiors present unique manufacturing challenges. Internal tooling, generally referred to as cores or mandrels, are used to create the hollow features in a structure. Depending on the geometry, some internal tooling can be easily removed after molding. However, any configuration that traps the mandrel inside, requires sacrificial tooling\* or a more complex, collapsible or inflatable tool.

\*Sacrificial tooling - tooling that is only used once and must be broken or washed out.

Current sacrificial tooling technology uses materials such as eutectic salts, ceramics, cast urethanes and other similar materials. These options present many challenges, including:

- Difficult to handle due to fragile materials
- Require additional tooling to produce
- Limits design freedom due to production or removal methods

FDM® (fused deposition modeling) sacrificial tooling, can dramatically streamline the production process for complicated composite parts with hollow interiors. Stratasys FDM technology uses a proprietary dissolvable thermoplastic material called ST130™, which enables the production of complex composite parts without a bonded seam or any additional support tooling. Furthermore, the dissolvable nature of ST130 enables hands-free mandrel removal, reducing the need for touch labor and reducing cost. Table 1 shows a comparison of traditional sacrificial tooling approaches to FDM tooling.

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	FDM Sacrificial Tooling	Silicone Bladder Over Foam	Eutectic Salt/Sand Patterns	Ceramic	Urethane	Clamshell Tooling
NO PRE-PROCESS TOOLING	✓	---	---	---	---	✓
HANDS-FREE REMOVAL	✓	---	✓	---	○	---
TEMPERATURE RESISTANT UP TO 250 °F (121°C)	✓	---	---	✓	○	✓
HIGH PRESSURE RESISTANT	✓	---	---	✓	○	✓
MINIMAL MANUAL LABOR	✓	○	○	○	○	---
NO BONDING REQUIRED	✓	✓	✓	✓	---	---
ROBUST TO SURVIVE ROUGH HANDLING	✓	---	---	○	✓	✓
SHORT LEAD TIME	✓	○	---	---	○	---
DIMENSIONALLY STABLE	✓	○	---	✓	✓	✓

Key: ✓ = Yes; ○ = Partial; --- = No

Table 1: FDM sacrificial tooling provides additional benefits and ease of use over traditional tooling methods.

### APPLICATION BEST FITS

FDM sacrificial tooling is best suited for composite fabrication applications where the lay-up process would fully enclose the tool, making removal especially difficult using multi-piece, collapsible tooling or where the tooling is impossible to retrieve due to a lack of physical access. FDM tooling replaces eutectic salt or similar wash-out tooling materials as well as other difficult composite manufacturing methods. ST130 is well-suited for the manufacture of complicated tubes, ducts, and fairings.

Business rational is achieved by the inherent low-volume production environment this application serves. Lead times for FDM tooling are typically significantly shorter than that of existing technologies. FDM technology is often able to reduce traditional tooling lead times of weeks or months to just days. This enables on-demand tooling fabrication, rapid design iteration, and a streamlining of the supply chain.

Sacrificial tooling with ST130 is a good fit for composite parts cured at or below 250 °F (121 °C) and up to 90 psi if the temperature

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remains under 210 °F (98 °C). If a higher temperature cure cycle is required, the ST130 material can still be used successfully, provided it is possible to cure the composite part in two stages. The first stage would be performed at lower temperature (and potentially higher pressure) to cure the part sufficiently for handling, followed by a second stage post-cure at a higher temperature to ensure complete cure of the composite structure. Temperatures above the recommended limits during the second stage will likely deform the tool. As long as the composite part is sufficiently cured and will not deflect under the second stage post-cure conditions, no impact on final part quality has been observed.

For cure cycles above 250 °F that cannot utilize a two stage cure, Stratasys ULTEM™ 1010 resin support material is used as a non-soluble, breakout mandrel. This approach has been demonstrated to be very successful for temperatures up to approximately 400 °F, provided the part geometry provides sufficient access for tool removal after cure. Contact your local Stratasys representative for more information on high temperature sacrificial tooling.

### TOOL DESIGN

The primary material characteristics for ST130 that should be considered during tool design include the coefficient of thermal expansion (CTE) and the cure temperature and pressure pairings listed in Table 2.

CONSIDERATION	REFERENCE
<b>CURE TEMPERATURE AND PRESSURE</b>	<ul style="list-style-type: none"><li>• Up to 250 °F (121 °C) with little to no pressure</li><li>• 90 psi (620 kPa) up to 210 °F (98 °C)</li></ul>
<b>COEFFICIENT OF THERMAL EXPANSION</b>	<ul style="list-style-type: none"><li>• 59 x 10<sup>-6</sup> in/in-°F (140-212 °F)</li><li>• 98 x 10<sup>-6</sup> in/in-°F (212-266 °F)</li><li>• 106 μm/m- °C (60-100 °C)</li><li>• 176 μm/m- °C (100-130 °C)</li></ul>

Table 2

Beyond material characteristics, two main design styles should be considered for FDM sacrificial tooling. The first is a sparse interior fill pattern and the second is shell style. Sparse style is the most common and provides optimal balance among build time, dissolution and tool strength. Shell style uses less build material and is most effective with an envelope bagging process.

The design of a sparse tool starts with a CAD model of the final composite part. The sacrificial tool model is created by extracting the primary surface from the composite part and filling the internal cavity of the composite model to create a solid body. Hiding the composite model displays the resulting sacrificial tool model.

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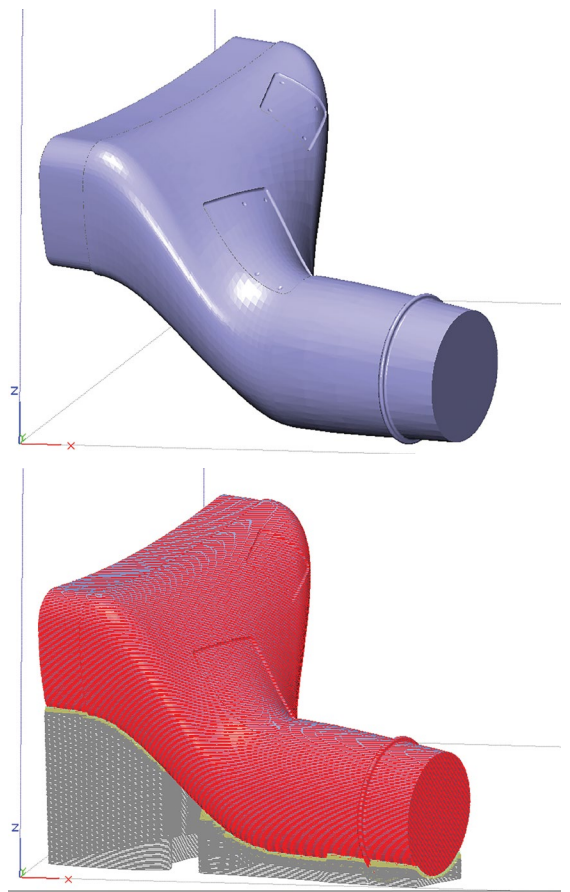
A shell tool is designed in a similar manner but employs an additional shelling step. Once the solid CAD tooling geometry is developed, it is shelled to create a body with a wall thickness appropriate for the pressures and temperatures used during the composite fabrication process.

Tools that are larger than the 3D printer's build chamber are sectioned into multiple components. The pieces are then joined together using standard FDM-joining techniques to create the final tool. Lap joints are recommended to ensure sufficient surface area for bonding though other types of joints such as dovetail, tongue and groove and butt joints can also be used.

### BUILDING FOR OPTIMAL RESULTS

Tools can be built in a vertical, horizontal or other orientation, which is an arbitrarily-chosen position based on the geometry of the part. Which orientation to choose is very important because it affects build speed, support material requirements, surface quality and overall part performance. Orientation also impacts tool surface finish, so tool design intent and surface finish requirements should be considered beforehand to determine the best build orientation.

For example, a part with curved surfaces may result in greater stair-stepping in one orientation compared with another, requiring more post-processing to achieve a smooth surface finish. The key for success is striking a balance that minimizes material use and post-processing time while maintaining adequate strength of the resultant tool.



Positioning the model in the appropriate build orientation to achieve the desired finish properties.



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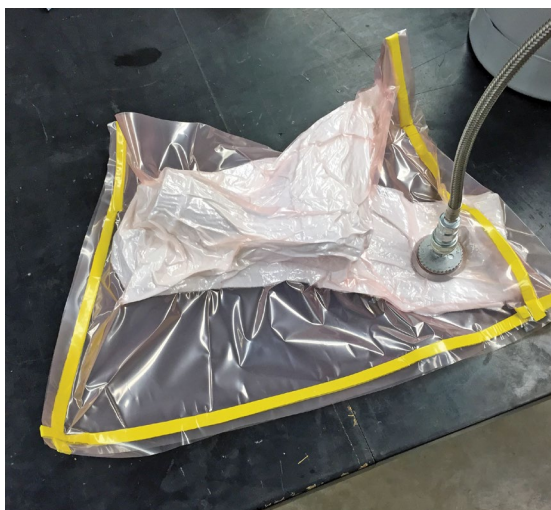
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FDM composite tools may need to be finished after they're built to impart a smooth surface to the composite part. They can be hand-sanded or media-blasted using walnut shells or baking soda. Once smoothed, they should be sealed to avoid resin starvation on the composite part due to resin seeping into the tool.

### COMPOSITE CONSOLIDATION

FDM sacrificial tools are compatible with several consolidation methods including vacuum and envelope bagging with autoclave cure, shrink tubing and shrink tape.

Vacuum bagging with autoclave pressures has been successfully achieved up to 90 psi at 210 °C. Above this temperature the pressure must be reduced to prevent tool damage. Envelope bagging is an economical consolidation method although it doesn't permit good control of the outer surface finish.



A composite part under vacuum using an envelope bagging process.

Shrink tubing and shrink tape are similar, low-pressure consolidation methods that don't require vacuum or autoclave. Shrink tubing results in a good finish on external surfaces and while shrink wrap offers better surface finish results compared to envelope bagging, it will impart a spiral pattern on the part.

Once the composite part has cured, the combination of the sacrificial tool covered with composite lay-up is submerged in a detergent bath to dissolve the tool. The result is a hollow composite part, produced quickly with minimal labor.



The mandrel used to form this composite brake duct has been washed out, leaving the resultant hollow part.

## SUMMARY

Advancements in the properties of 3D printed materials are enabling a host of new applications that allow users to realize tremendous value beyond prototyping. Stratasys FDM material ST130 offers a fast, robust, and cost-effective alternative to traditional sacrificial tooling technologies. For more information on 3D printed composite tooling visit the Stratasys [website](#) and download the available [design guides](#).



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**HEADQUARTERS**

7665 Commerce Way, Eden Prairie, MN 55344

+1 800 801 6491 (US Toll Free)

+1 952 937 3000 (Intl)

+1 952 937 0070 (Fax)

2 Holtzman St., Science Park, PO Box 2496

Rehovot 76124, Israel

+972 74 745 4000

+972 74 745 5000 (Fax)

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