FDM SACRIFICIAL COMPOSITE TOOLING

Stratasys Composite Tooling Team

23 August 2016

stratasys

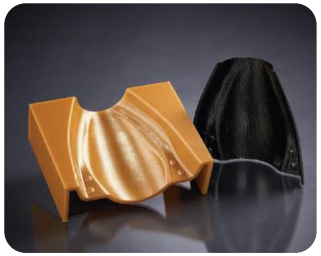
Agenda

- Composite Tooling Applications
- Traditional Composite Tooling Review
- Stratasys Sacrificial Tooling Solution
- Technical Considerations
- Success Stories

stratasys

Composite Tooling Applications

Lay-Up Tooling

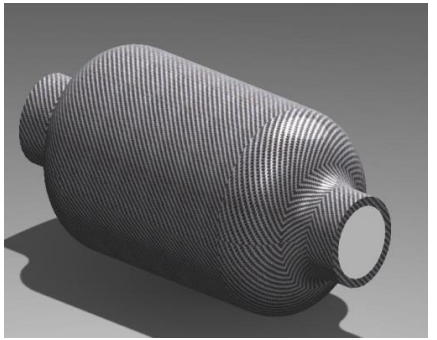


Sacrificial (Wash-Out) Tooling

Sacrificial Tooling Applications and Uses

Hollow composite part production

- Ducts and tubing
  - Aerospace, automotive, motorsports, prosthetics
- Tanks and reservoirs
  - Aerospace, automotive, motorsports
- Complex / hollow structural members
  - Aerospace, automotive, motorsports, sporting goods, prosthetics



Tanks and reservoirs

Hollow composite parts/structures can be manufactured through a variety of processes

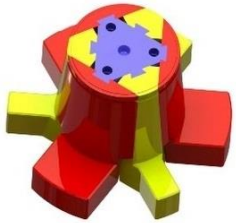
- Filament-winding and Automated Fiber Placement (AFP)
- Hand lay-up
- Resin-transfer molding (RTM)
- Vacuum assisted resin-transfer molding (VARTM)

Filament-wound duct (Top = Sacrificial Tool, Bottom = Carbon fiber wound over tool)

Traditional Tooling Methods – Challenges

Key Challenges for Traditional Tooling Techniques

- Collapsible tooling/Multi-piece bonded assemblies
  - High design complexity
  - Geometric restrictions
  - Increased labor costs and extended lead times
- Inflatable and shape-memory bladders
  - Production tooling/machining is required to create bladders/cores
  - Increase costs and extended lead times
- Wash-out tooling
  - Traditionally fragile/brittle
  - Tooling/machining is required to manufacture cores
  - Unstable material properties and high shrinkage during the curing process can be problematic
- Closed clamshell molds with/without removable tooling
  - Potentially weak visible seams at mold parting line
  - May require tooling to create clamshell molds
  - Increased labor costs and extended lead times



Collapsible Multi-Piece Tool

Bladder Molds

Traditional Wash-out Tool

Stratasys Sacrificial Tooling Solution

FDM Sacrificial Tooling Overview

Easy-to-produce, cost-effective wash-out tooling for complex, trapped geometries

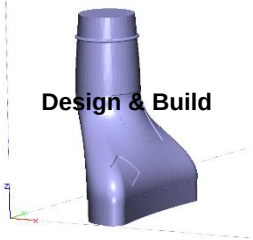
- Wash-out solutions capable up to 250 °F
- Break-away solutions capable of >350 °F

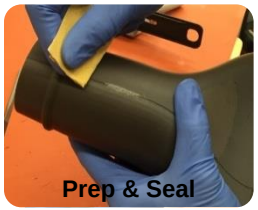
Eliminates complexity of traditional trapped tooling methods

- No casting, molding, machining…no mess
- No material phase changes (e.g., eutectic salts)
- No complex, multi-piece, collapsible tools or inflatable bladders
- No steep learning curves or extensive prior expertise required

Tools available in hours, not weeks or months

Iterate, change and modify designs with relative ease





New Sacrificial Tooling Solution: ST-130

- Stratasys has developed ST-130, a model material tuned specifically for the sacrificial tooling application
  - ST-130 utilizes new fill patterns that provide higher crush strength, improved fluid flow and reduced washout time
  - A specialty tip, T20B, was developed for ST-130 to optimize build quality
- ST-130 is dissolvable in WaterWorks™ or EcoWorks solutions, similar to Stratasys support materials
- ST-130 simplifies use relative to existing urethane or salt-based tooling methods and allows for rapid, low-cost design iteration and flexibility
- Available on the Fortus 450mc and 900mc platforms

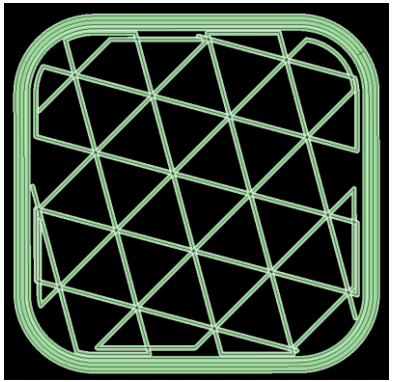
Sacrificial Material	~Max. Cure Temp	T_G
ST-130	250 °F (120 °C)	266°F (130 °C)

New T20B tip design

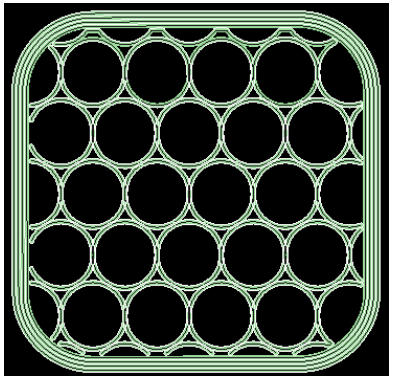
New Sparse fill Pattern

New Fill Patterns

- New fill patterns, specifically developed for ST-130 provide:
  - **Higher crush strength**
  - **Improved fluid flow**
  - **Reduced washout time**
- New fill patterns recommended for ST-130 are:
  - **Permeable triangular:** Best balance of build time and strength and is therefore the default fill pattern
  - **Permeable tubular**: Stronger (most geometries) but increases build time
- ST-130 dissolves in the WaterWorks™ or EcoWorks solutions
  - Circulation of the detergent solution helps to significantly reduce dissolution times

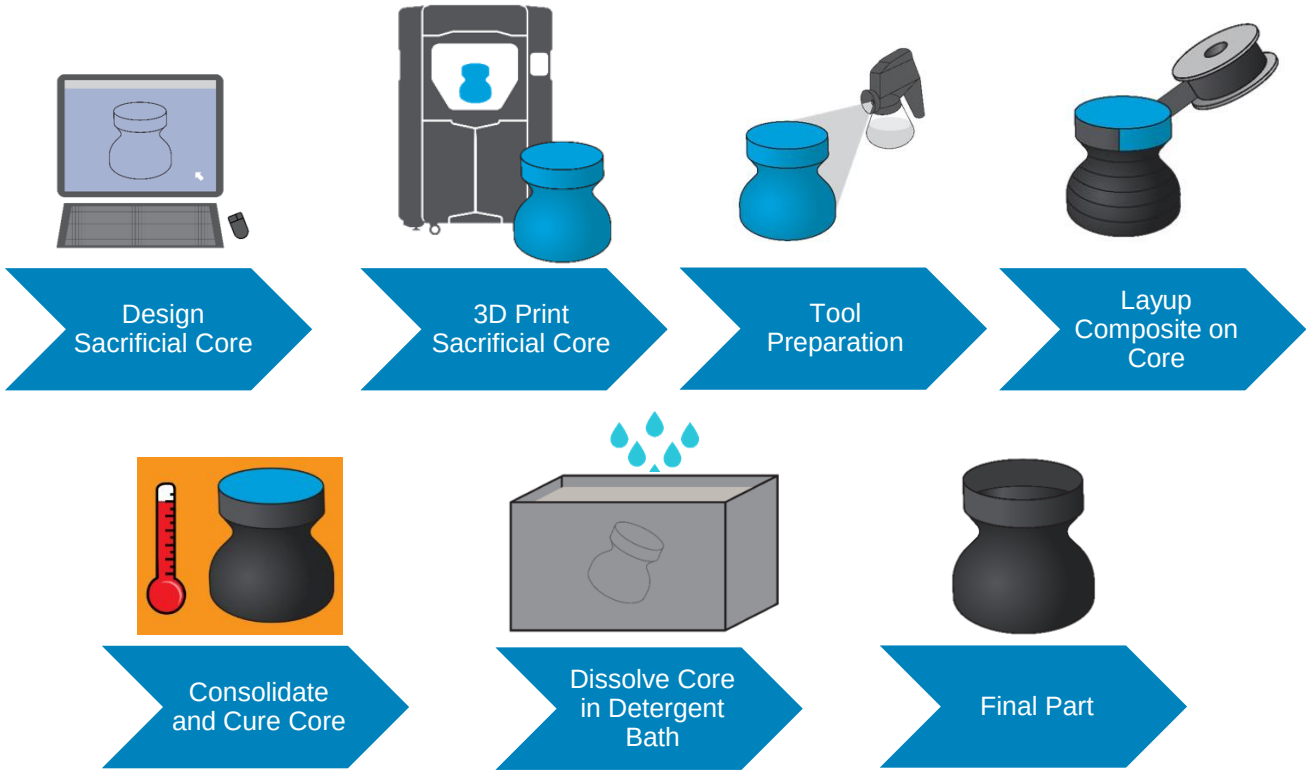


Permeable triangular



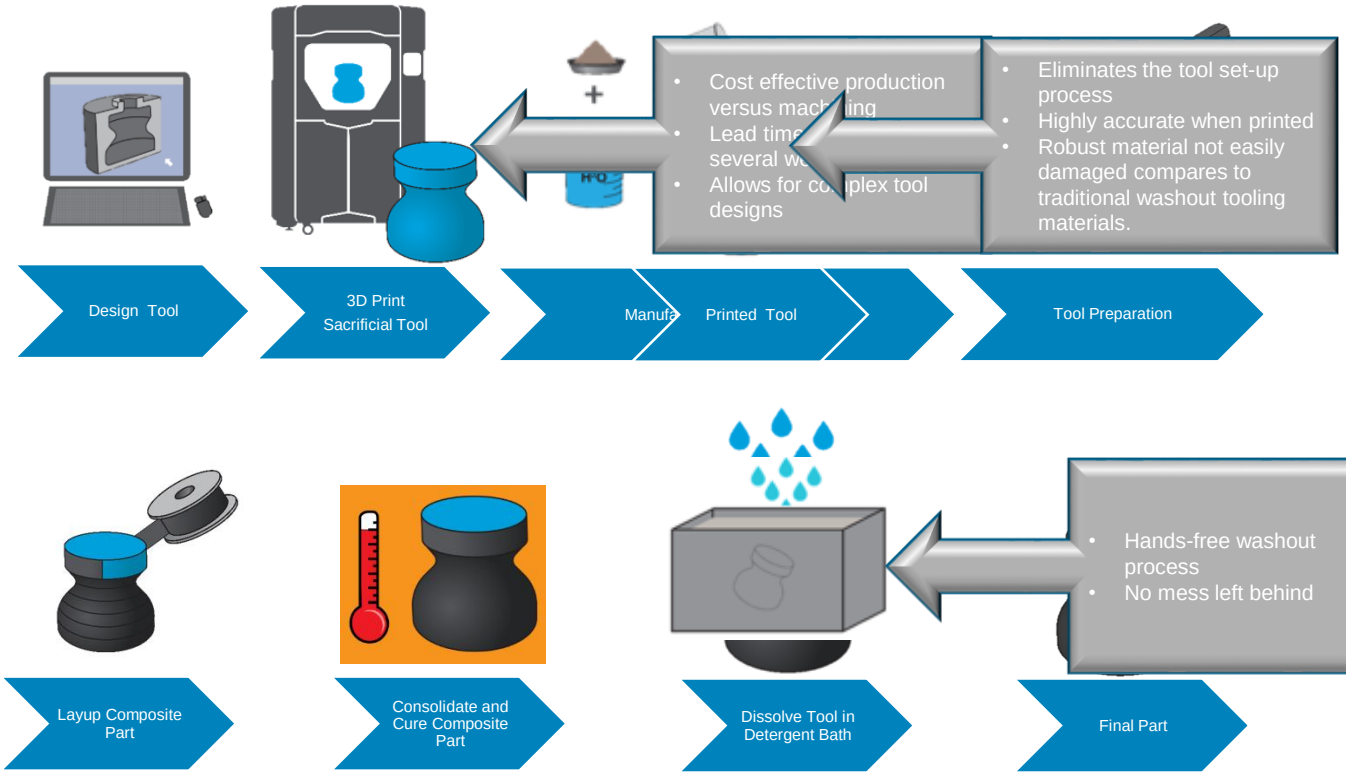
Permeable Tubular

Stratasys Sacrificial Tooling Process:



Process Comparison

Stratasys Sacrificial Tooling VS Traditional Washout Process



Tooling Solutions Comparison

	FDM Sacrificial Tooling	Bladder Inflation Molding	Eutectic Salt/Sand Patterns	Ceramic	Urethane	Clam Shell Tooling
No Pre-Process Tooling	✓	---	---	---	---	✓
Hands-Free Removal	✓	---	✓	---	O	---
Temperature Resistant up to 250 °F	✓	✓	✓	✓	O	✓
High Pressure Resistant	✓	✓	O	✓	O	✓
Minimal Manual Labor	✓	O	---	O	O	---
No Bonding Required	✓	✓	✓	✓	---	---
Robust to Survive Rough Handling	✓	---	---	O	✓	✓
Short Lead time	✓	O	---	---	O	---
Dimensionally Stable	✓	O	---	✓	✓	✓

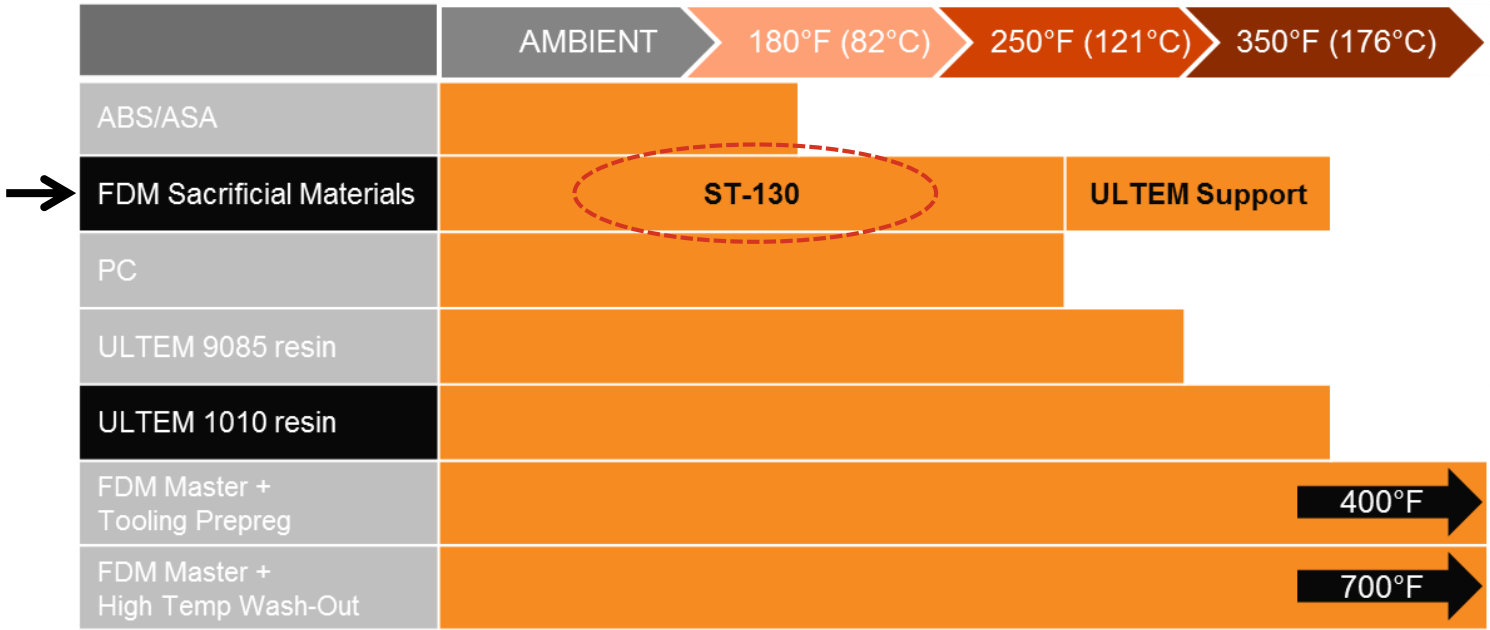
KEY	
Yes	✓
Partial	O
No	---

stratasys

Technical Considerations

Temperature Capabilities

- ST-130™ sacrificial tooling – wash-out material for complex / trapped tooling
- ULTEM™ 1010 Support – Not soluble but can be manually removed

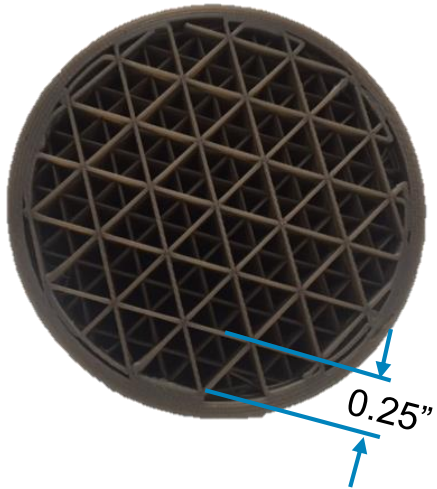


ULTEM is a registered trademark of SABIC or its affiliates or subsidiaries.

Air Gap vs Processing Capabilities

- The default and recommended air gap for ST-130 is 0.25” for Insight versions 11.0 and greater
  - Insight 10.8 has a default value of 0.4 inch that should be modified when using high consolidation pressures

- Additional testing is underway to further characterize the relationships between temperature and pressure capabilities
  - Proven capabilities – 90 psi @ 210°F with an air gap of 0.25 inch
  - For tools with larger cross-sectional areas, 90 psi @ 210°F using an air gap of 0.4 inch has been successfully demonstrated



Cure Temperature	Air Gap	Max. Consolidation Pressure
≤ 210°F	0.25 inch	90 psi
≤ 250°F	0.25 inch	Vacuum only

Fiber-Matrix Compatibility

- ST-130™ is compatible with most composite fiber and resin systems
- However, the Waterworks™ solution used to remove the tool can attack and weaken certain polyester resins
    - Consult the resin manufacturer’s specifications for compatibility with basic solutions

Interlayer Adhesion

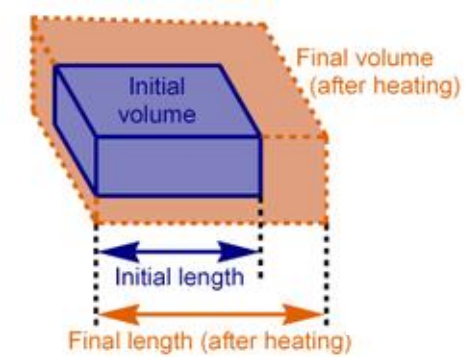
- Although ST-130 was developed to meet the high standards for model materials, it does have relatively low interlayer adhesion (z-strength) compared to traditional FDM materials
- Certain geometries may be susceptible to interlayer cracking (delamination), such as thin flanges and other fine features
- ST-130 can be bonded with a fast curing methacrylate or epoxy adhesive or hot-air welded
    - Plexus MA300 (methacrylate)
    - Henkel EA 9394 (epoxy)

Coefficient of Thermal Expansion (CTE)

What is CTE?

- Coefficient of Thermal Expansion
- Its a physical property that describes how a material will expand or contract based on a change in temperature

Material	CTE (in/in/°F)	
	140-212 °F	212-266 °F
ST-130	**59 x 10^{-6}**	**98 x 10^{-6}**
Carbon Fiber/Epoxy	0.0-6.0 x 10^{-6}	
Aluminum	12.9 x 10^{-6}	
Steel	9.6 x 10^{-6}	



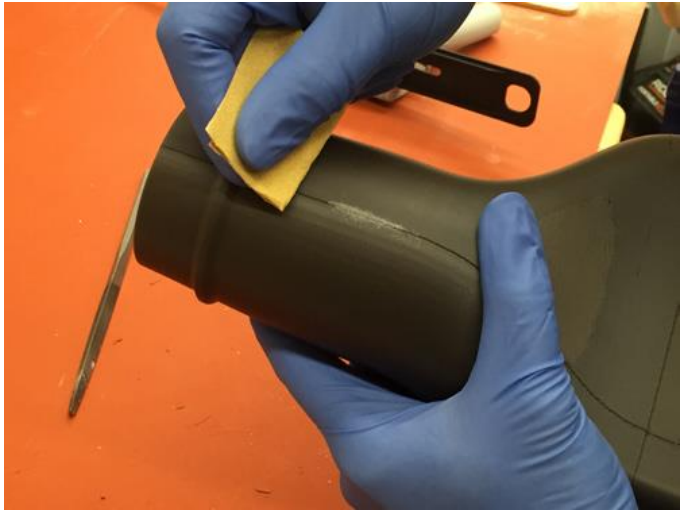
Why is CTE important?

- Impacts the final dimensions, shape, and performance of the composite part
- ST-130 is considered a high CTE material
- For most cases, ST-130 will be used for male tool shapes where addressing CTE in the design is more manageable and can even be used as an advantage to improve part consolidation

Tool Preparation and Dissolution

Smoothing Surfaces

- ST-130 can be hand-sanded with 120-600 grit sand paper to improve surface finish
- Surface finishes consistent with industry requirements (< 64 µin, Ra) are routinely achievable
- Alternatively, a grit/soda blaster maybe used with walnut shells or baking soda

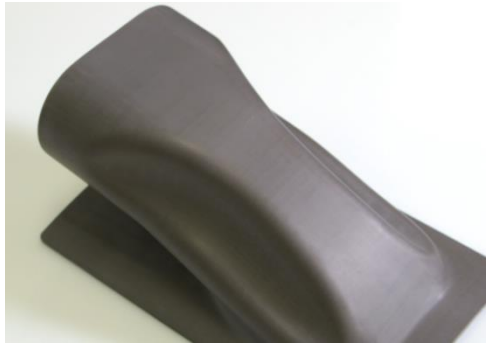


Sealing and Release Methods

- The resin from composite materials will seep into the layers of the sacrificial tool if it is not sealed / prepared properly
  - This can cause incomplete dissolution of the ST-130 material and produce a resin starved composite part
- Sealers, such as Zyvax Quickskin, or an equivalent sealing system, should be brushed or rolled onto the tool
  - Follow the sealer manufacturers recommendations with one exception:

    Do not treat the surface of ST-130 with acetone as it will degrade the material
    - Isopropyl alcohol is recommended as an alternative
- **Prepare tools no more than 3 days prior to lay-up**
  - The chemicals in sealers and releases can cause mild degradation in the thermoplastic tool and weaken the compression strength of the tool
- Tools can also be sealed with epoxy resins, release tapes & films, and shrink tapes

Typical Quickskin-Sealed Surface



Typical Epoxy-Sealed Surface

Cap Layer Removal and Dissolution

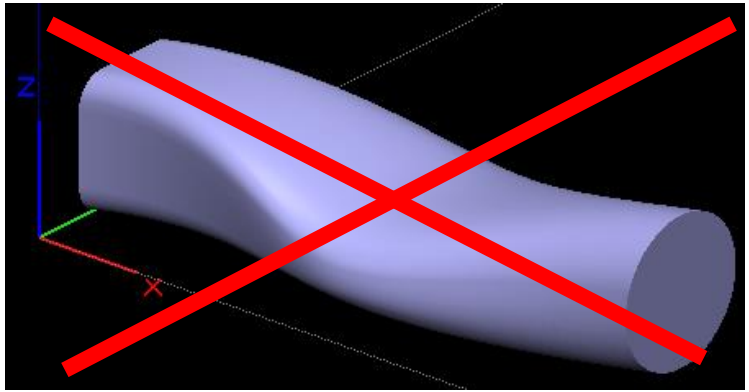
- ST-130 is soluble in the WaterWorks and EcoWorks Solutions
- Exposed faces of the sacrificial tool should be broken open to expose the sparse interior to the detergent bath
  - This allows for quicker access to the interior of the tool and accelerates the dissolving process
- The internal fill can also be exposed by drilling holes through the cap layers with a large diameter drill bit
- Sections of the tool can be manually extracted if they are easily accessible
- Circulation of the detergent is critical to reducing dissolution time
  - Once the tool has completely dissolved thoroughly rinse the composite part with tap water to remove all of the detergent solution

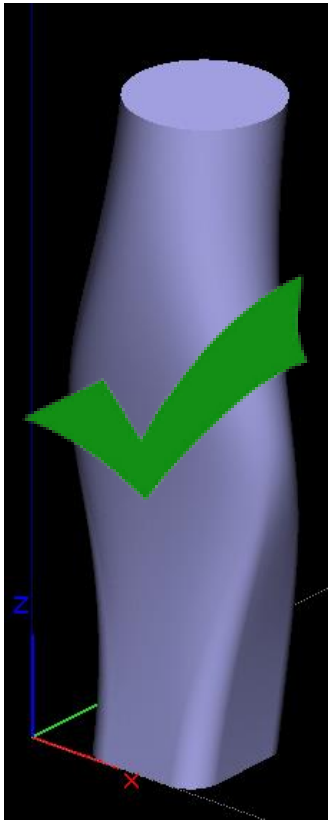
Technical Considerations

Insight Tips & Tricks for ST-130

Insight Tips & Tricks – Build Orientation

- Build orientation is critical to optimizing build time, surface quality, tool durability, and fluid flow during the washout process
- In most cases, building the most critical surface/contour along the Z-axis will optimize surface quality and fluid flow during wash-out

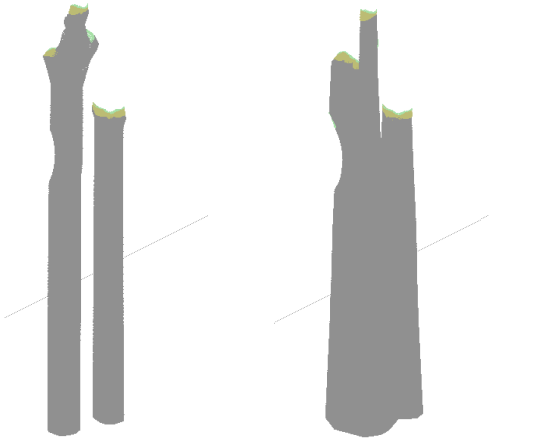




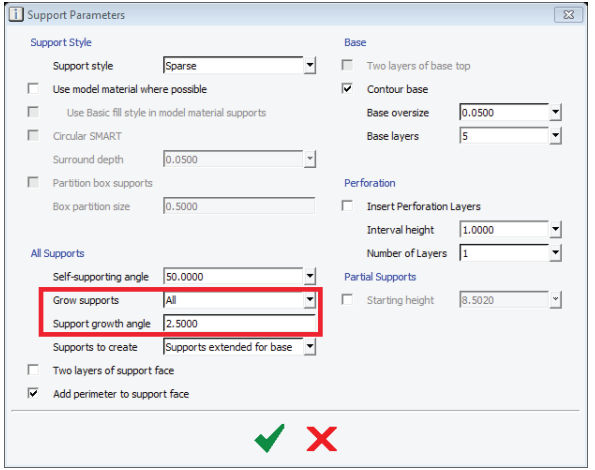
Insight Tips & Tricks – Support Generation

- Smart support structures should be used by default for ST-130 Tools
  - Caution – tall narrow ST-130 support structures are susceptible to tipping over during building and should be avoided

- When tall narrow support structures are needed to support specific features, utilize the grow supports option to prevent towers from tipping over

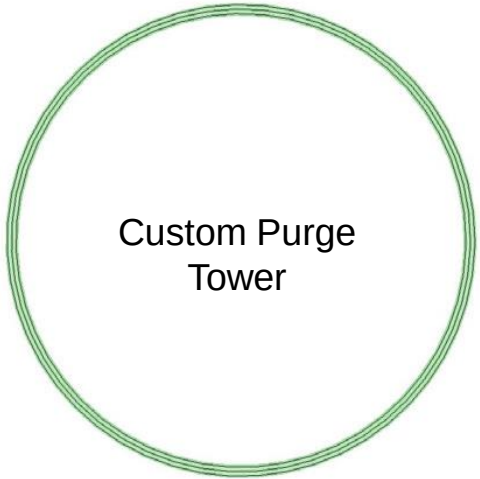


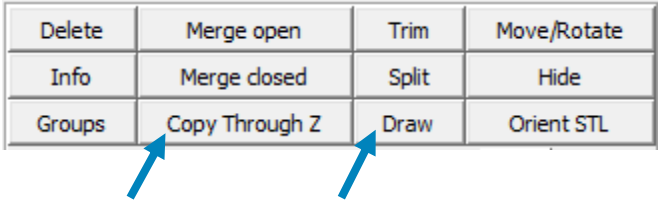
Smart support | Grow support



Insight Tips & Tricks – Purge Towers

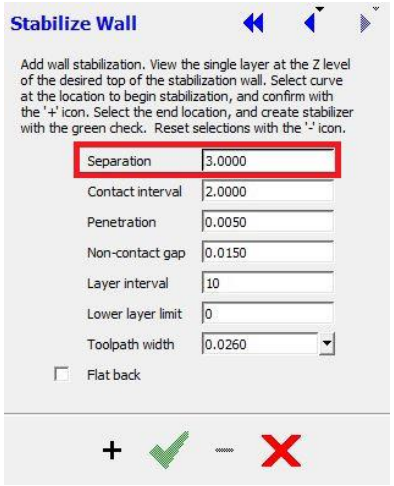
- Purge towers are strongly encouraged for all builds to maximize part quality
- The default purge tower in control center can be susceptible to tipping over on parts taller than 3 inches
- Custom purge towers are recommended
  - Generate 2 inch circular purge towers with the draw and Copy through Z commands in Insight
  - Build purge towers with 3 contours

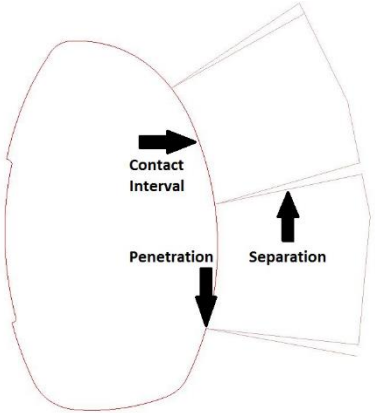




Insight Tips & Tricks – Stabilizer Walls

- Stabilizer walls are single-bead structures that help stabilize the tool during the build
- The stabilizer wall separation value controls how far back the wall is separated from the sacrificial tool
- For ST-130 tools, the default separation value of 2 inches should be increased to 3 inches to improve bonding to the build sheet
  - While processing ST-130 files in Insight, stabilizer walls will appear to have no support material. However, the machine automatically adds base layers when the file is sent to the printer





Guides to Success

Composite Tooling Design Guides

[Sacrificial Tooling and Mandrels for Composite Part Fabrication Design Guide]

[FDM for Composite Tooling Design Guide]

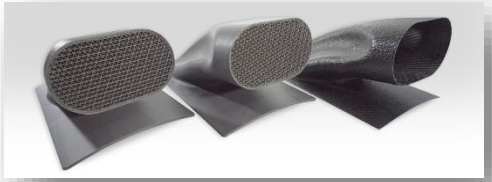
Success Stories

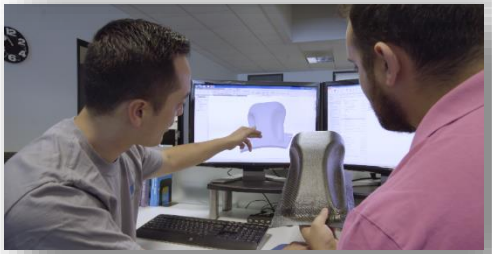
Customer Success Story – Sacrificial Tooling

Swift Engineering Inc.

Enabling an advanced product development team through complex part fabrication

- Aero inlet duct with a complex, trapped-tool geometry
- Wash-out tooling material (ST-130) used in place of multi-piece bonded assembly and traditional wash-out tooling materials
- From concept design to composite part in < 1 week
  - FDM build time is < 24 hours
  - Default porous triangle fill pattern – optimized for autoclave curing and tool dissolution
  - Low temperature (<200°F), 90 psi cure cycle





Customer Success Story – Sacrificial Tooling

FDM Empowers Champion Motorsports to Create Strong, Beautiful Composite Parts for Porsche

- Automotive turbo inlet ducts with complex trapped-tool geometry
- Allowed for single-piece tool construction while still achieving interior and exterior surface finishes
- Enabled economic low-volume production tooling
- Tooling created in days versus months
- Stratasys sacrificial tooling reduced overall production cost

Carbon fiber inlet ducts.