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THE 3D PRINTING SOLUTIONS COMPANY

Sacrificial Tools with Stratasys FDM Technology

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Stratasys

For more than 25 years, Stratasys has been at the forefront of 3D printing and additive manufacturing innovation.

HEADQUARTERED IN EDEN PRAIRIE, MINNESOTA AND REHOVOT, ISRAEL

OVER **800** GRANTED OR PENDING ADDITIVE MANUFACTURING **PATENTS GLOBALLY**

146024 CUMULATIVE SYSTEMS SOLD*
100000 Makerbot**

OVER 30 TECHNOLOGY AND LEADERSHIP AWARDS

PUBLICALLY TRADED ON **NASDAQ (SSYS)**

$696 MILLIONS REVENUE 2015

*31 December 2015
**5 April 2016

Shaping Performance Motorsports

"Several really complex design elements would have been almost impossible to replicate through any other method of production."

Edward Green, Mission Motors

Shaping the Art and Science of Travel

"This game-changing technology also decreases total energy used in production by up to 90 percent compared to traditional methods."

Peter Sander, Head of Emerging Technologies and Concepts at Airbus

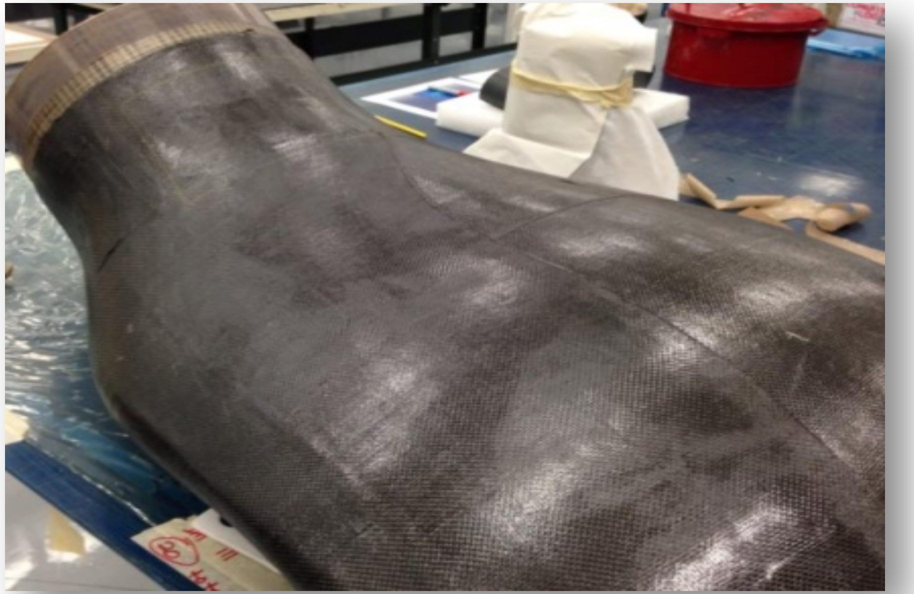
Sacrificial Cores & Mandrels: Application Overview

<u>**Complex**</u> hollow composite part production

- Ducts and tubing
- Tanks and reservoirs
- Tubular or hollow structural members

Sacrificial Cores & Mandrels: Application Overview

Processes
- Filament-wound composites
- Pre-preg, wet lay-up, resin-transfer



Trapped Molds

Hollow composites

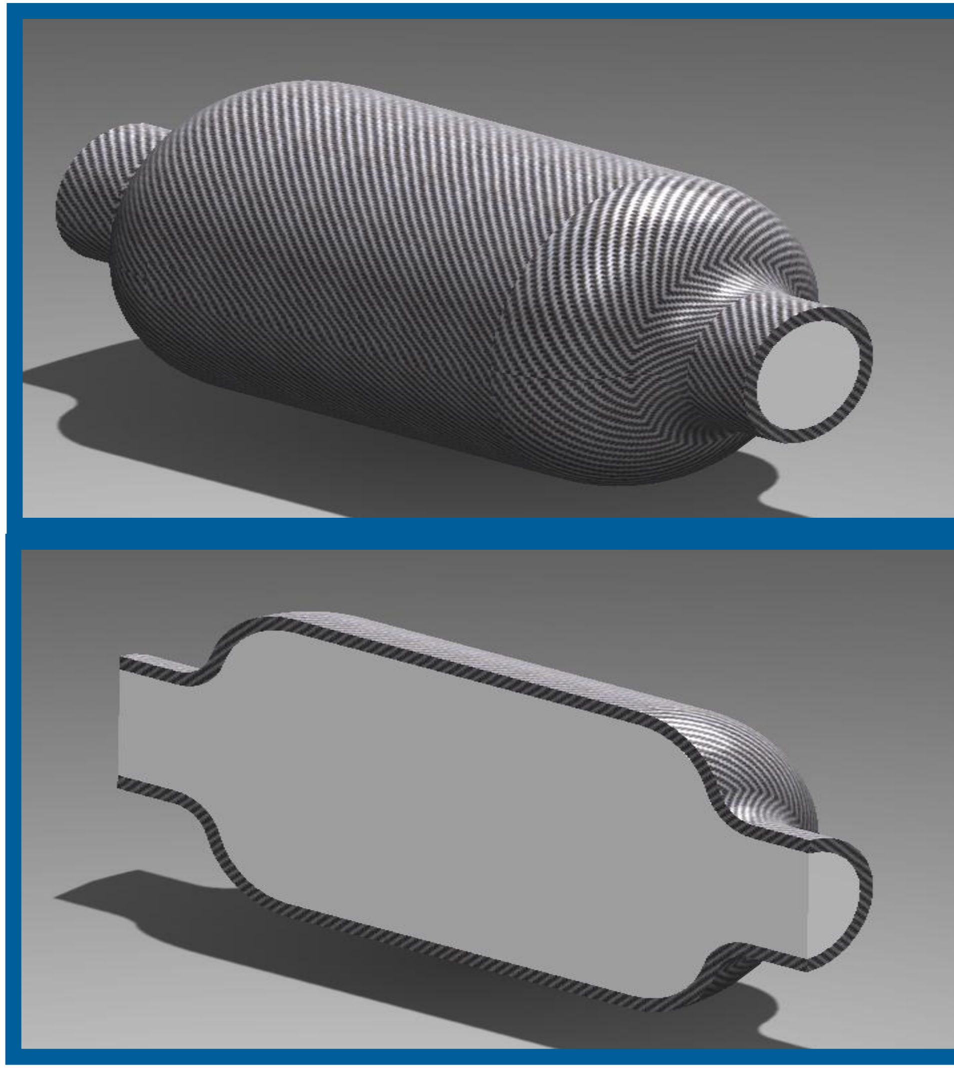
Geometry traps core

Core must be removable

- Soluble material
- Collapsible material

Compatible with composite process

- Temperature
- Pressure



Traditional Solutions

Several options

Geometry and manufacturing process dependant

Common traditional methods

- Eutectic salts
- Soluble ceramics
- Flexible urethanes
- Clamshell tooling

Eutectic Salt Cores

Pros

- Very hard, durable
- High temperature
- High pressure

Cons

- Requires metal casting mold
- Difficult to remove
  - High temperature water
  - High pressure streams
  - Chisels
- High scrap rate

Soluble Ceramic Cores

Pros

- High temperature
- Gentle water dissolve removal
- Good surface finish

Cons

- Cast (machined mold)
- Very brittle
- Long / thin parts don’t work
- Limited manufacturing process compatibility

Flexible Urethane

Pros

- Gentle removal process
- Good surface finish
- Reusable core

Cons

- Cast (machined mold)
- High CTE
- Simple geometries
- Requires solid, removable insert

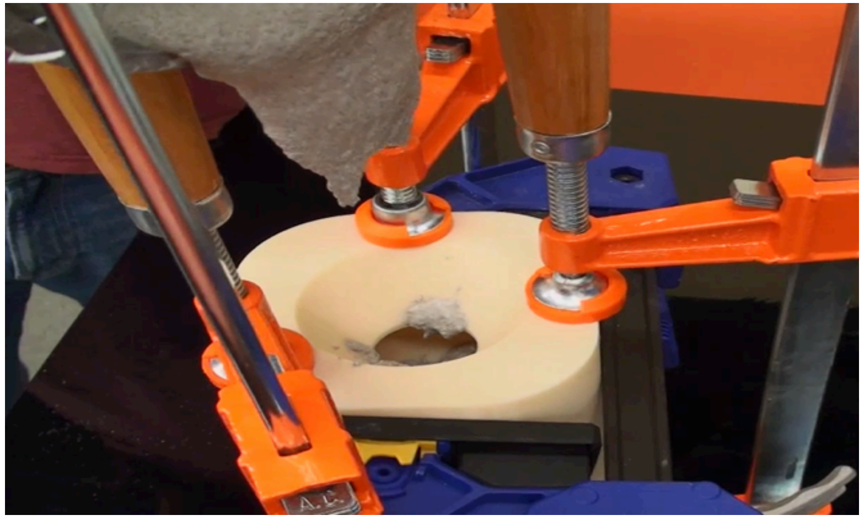
Cores & Mandrels: Traditional Process

Production of cores

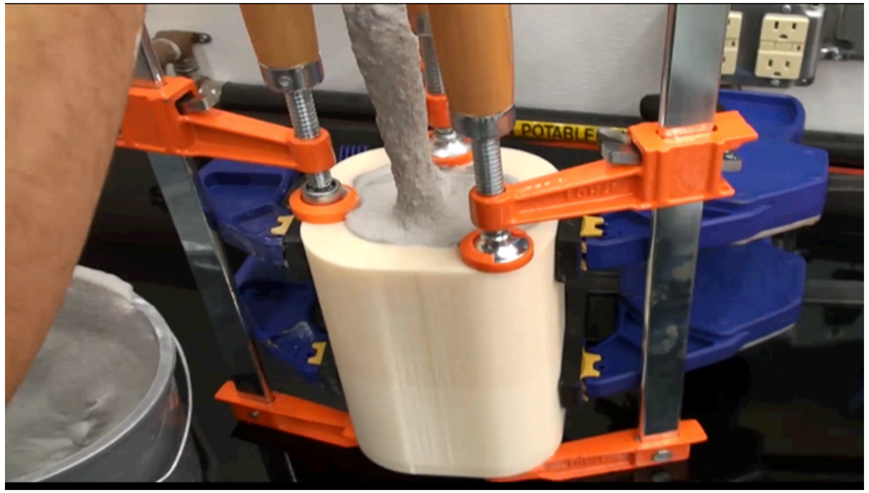
- Machined tooling to cast cores
- Machined multi-piece removable core

Issues:

- Geometry limitations
- Inconsistent parts
- Lack of repeatability



Core mold.



Forming sacrificial core in mold.

Clamshell Tooling (Lay up halves and bond)

Production of clamshell tooling

- Option 1: Pattern-based mold
  - Pull mold from pattern
- Option 2: Machined mold

Pros

- Reusable
- Good external surface finish

Cons

- Geometry limitations
- Tooling lead time
- Many mold components
- Seams when access is limited
- Internal surface finish, wrinkles

Clamshell tooling with pattern.

Clamshell tool after assembly.

FDM Sacrificial Tools

Replaces clamshell tooling
- Eliminates seams – strengthens part
- Improves internal surface accuracy

Replaces traditional core types
- Eliminates tooling for core and casting of core
  - Automated core production
  - Reduced time and labor
  - Core/mandrel dissolved after part cures
- Improves consistency, accuracy and strength
- Easy core removal (washes or breaks away)
- Sparse or solid interiors to optimize wash-out time and strength
- Epoxy resin compatible
- No changes to manufacturing process

FDM sacrificial core (SR-100™).

Carbon fiber manifold.

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Sacrificial Cores & Mandrels: Competitive Overview*

	Ease of Removal	Consistency	Low Production Labor	Design Freedom	Core Strength	Requires Dedicated Tooling
Water Soluble	üüüü	ü	–	ü	ü	Yes
Removable Cores	–	üüüü	(Reusable)	–	üüüü	No
Shape Memory Bladders	üüü	–	ü	–	üüü	Yes
Sand Cores	ü	üü	–	ü	ü	Yes
Eutectic Salts	–	üü	–	ü	üüü	Yes
FDM	üüü	üüü	üüü	üüüü	üüü	No

Compatibility (– = N/A, ü = Low, üü = Good, üüü = Great):

* Subjective qualities based on expert analysis

Some References

Motorsports

Automotive – Performance

Bicycles

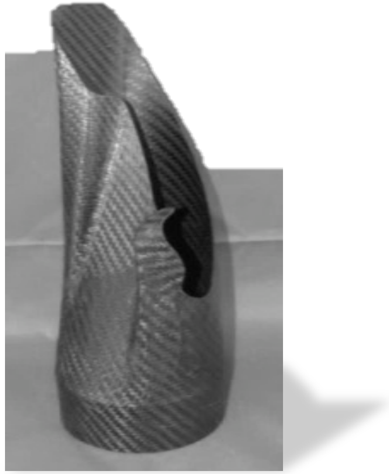
Motorsports

Aerospace

Automotive

Sacrificial Cores & Mandrels

Sacrificial Cores & Mandrels: FDM Benefits



Time and cost savings

- Up to 95% reduction
- As little as 1 day for concept to part realization

Labor reduction

- Less tooling/setup & hands-free core creation
- No bonding of sections

Improved composite parts

- Single-piece construction
- Include integrated hardware
- Control internal surface finish and accuracy

Lower risk

- Minimal investment & easy to modify (no tooling)
- Improved consistency and yield of cores

Typical time and cost savings derived from numerous end-user analysis, testimonials and feedback. Actual savings may vary based upon numerous factors, including traditional time/cost, part geometry and utilized technology.

Case Study
CPC (Modena)

Composite Manufacturing

Conventional Manufacturing

- 3D Design
- Mould Design
- Mould Machining
- Hand lay-up
- Bag and cure part
- Final part

FDM Composite Application

3D Design

Consumable Core Design

Core in FDM Support

Hand lay-up

Bag and cure part

Break the core

Final part

Case study: Double airduct

FDM
Composite Application

Consumable Core Design (15 min)
Build consumable core (4.5 h)
Hand lay-up (15 min)
Bag and cure part (2.5 h)
Break the core (30 min)
Final part

Case Study
Champion Motorsport

Sacrificial Cores & Mandrels: Case Study – Champion Motorsport

Porsche 997 Turbo inlet duct, Y-pipe, manifold

- Better airflow
- Lighter

Tried many approaches – none were sellable

- Bonded halves
- Molded sand core

FDM sacrificial core method

- Seam-free construction w/ consistent quality
- Control over interior and exterior

FDM composite core benefits

- ~85% faster
- ~85% less expensive

Carbon fiber inlet ducts.

Method	Cost	Time
Traditional	unusable	unusable
FDM core*	$150	1 day
Savings	**~85%**	**~85%**

* Produced in-house.

Sacrificial Cores & Mandrels: Compatibility

Resin systems
- Consult resin manufacturer for compatibility
  - Core is dissolved in a base solution
  - Most epoxies are compatible

Consolidation methods
- Vacuum/autoclave
  < 121 °C (250 °F) & 550 kPa (80 psi)
  - Envelope bagging
  - Through-core bagging
- Shrink tape/tubing
- Bladders

Temperature
- SR-30: 93 °C
- SR-100: 138 °C
- Ultem S1: 175 °C

Pre-preg epoxy resin system.

Thermal cure of vacuum-bagged composite part.

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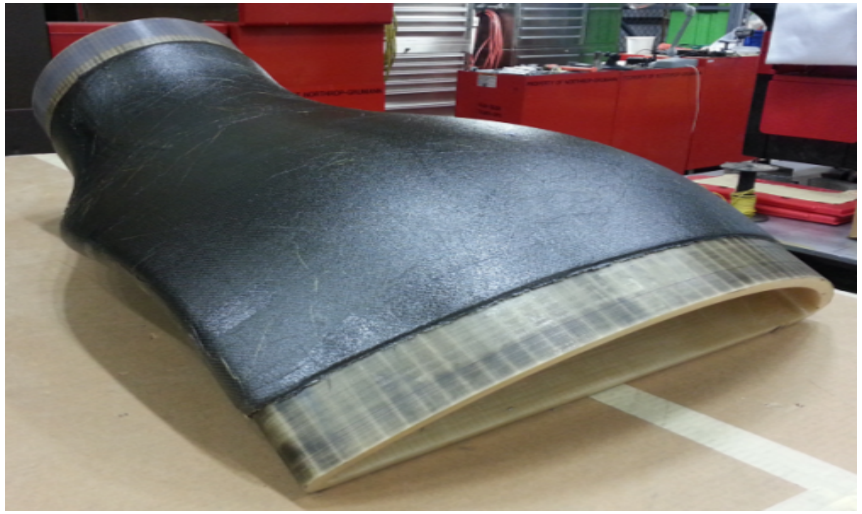
Sacrificial Cores & Mandrels: Materials

Materials

- ULTEM® 9085 resin support (S1) (alternative)
  - Break-away
  - Higher cure temperatures
    - < 175 °C (350 °F)
  - Compatible with aluminum inserts

Process

- ULTEM® 9085 resin support
  - Build core/mandrel
  - Seal core
  - Consolidate & cure composite
  - Apply acetone
  - Manually remove core/mandrel
    - Does not dissolve
    - Requires good access



Cured composite on ULTEM S1 core.

ULTEM S1 core break out.

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Thank You