Additive Manufacturing Composite Materials for Automotive Product Development

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Mission

- Develop new **materials and process technologies** that grow 3D Printing adoption in **new markets and applications**.

- Technology developer for most Stratasys thermoplastic 3D printers
  - Dimension™, FORTUS™ and Makerbot FDM platforms

- Commercial products and custom products
01 FDM 3DP Process overview
02 Rapid prototyping examples
03 Composite applications with existing materials
04 Next Generation composite materials
FDM Process Overview

1. CAD or Reverse Engineering Data
2. Manufacture w/ FDM
3. Remove Supports
Automotive Rapid Prototyping

Bumper Fascia for exhaust gas flow testing & layout confirmation

- Built from Polycarbonate in 5 sections, solvent bonded
- 2.5mm thick with all mounting points from production data.
- 4.5 days runtime in two 900mc machines.
- Material cost; $3k
- Existing mounting data built onto B-surface for proper mounting.
PPSF material
Masking hole plugs
ABS bead blast
Cotronics Stainless steel paint
Metal inserts
Test run engine
Data to Dyno, 3 days total!
Durable Stable Parts

Inserts for wheel aero testing (actual build of 18 pieces)

- Post processing time: 5 minutes
- Tested on-vehicle at highway speeds with no failures
01  FDM 3DP Process overview
02  Rapid prototyping examples
03  Composite applications with existing materials
04  Next Generation composite materials
Composite Applications

FDM Composite Applications

Patterns

Lay Up / Cure Tools

Consumable Cores

Digitally Coordinated Tool Families

Masters
Pre Layup
Consolidation Tools
Low Temp
High Temp
Bonding Fixtures
Intensifiers
Caul Plates
Soluble Cores
Net Shaped Cores
Integrated Interfaces
Trim Tool
Drill Tool
Check Fixture
Composite Applications
Service Temperatures

<table>
<thead>
<tr>
<th>AMB</th>
<th>80°C</th>
<th>120°C</th>
<th>175°C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>180°F</td>
<td>250°F</td>
<td>350°F</td>
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</tbody>
</table>

- **ABS**
  - Low Temp Tools & Consumable Cores
  - Master Patterns

- **SR30**
  - Soluble Cores

- **PC**
  - Low Temp Cure Tools & Consumable Cores
  - Master Patterns
  - Trim & Drill Tools

- **ULTEM**
  - Med Temp Cure Tools & Consumable Cores
  - High Strength Trim & Drill Tools

- **PPSF**
  - High Temp Tools & Consumable Cores

- **ABS Master & Tooling Composites**
  - High Temp CTE Matched Tools

- **ABS Master & Nevada Composites**
  - High Temp CTE Matched Tools
  - High Temp CTE Matched Soluble Cores

- **200°C (400°F) Max**
- **+300°C (600°F)**
Proven Applications
- Fibers: Carbon, Glass, Kevlar
- Resin Systems: Epoxy & Polyester

Proven Tools
- Lay Up Tools
- Wash Out Cores [SR30]
  - Lay Up and Filament Winding
- Consumable Core
- Pre Lay Up Tool
- Pressure Intensifiers
- Master patterns for high temperature

Notes
- Surfacing Methods Available
- Release Agents Tested
- Coefficient Of Thermal Expansion [CTE] matching solutions available

FDM Material Selection Guide

<table>
<thead>
<tr>
<th>Material</th>
<th>Cure Temp °F</th>
<th>Autoclave Pressure PSI</th>
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</thead>
<tbody>
<tr>
<td>SR30</td>
<td>200</td>
<td>90</td>
</tr>
<tr>
<td>PC</td>
<td>200</td>
<td>90</td>
</tr>
<tr>
<td>ULTEM</td>
<td>250</td>
<td>90</td>
</tr>
<tr>
<td>PPSF</td>
<td>350</td>
<td>90</td>
</tr>
</tbody>
</table>
FDM Lay Up Tools

Ultem 9085 Hat Tool and Caul Plate 26.5”x 6.5”x 4.5”

Composite lay-up w/ Kevlar/Epoxy & Glass/Polyester resin & FDM Caul plate

Bonded tool & Caul plate with Hysol EA934

FDM tool fully bagged, ready for autoclave

350,° 50 psi autoclave, 2hr cycle
Composite Access Door

APPLICATION
• VRTM Composite Part Fabrication

TOOL
• Smart FDM VRTM Lay Up Tool
• Coordinated FDM Trim Tool

CAPABILITIES
• Carbon Fiber/ Foam Core/ 50A Epoxy
• Vacuum Pressure, 160°F Cure
• -55°F to +180°F part service temperature

BENEFITS
• Rapid low cost composite part fabrication
• Dual zone embedded surface temp monitoring
• Trim tool improved quality & cycle time
• Lights out in-house tool build
• 75-95% Cycle Time Reduction
• 70% Tool Cost Reduction
• Ergonomic light weight tool
FDM Male Lay Up Tool

FDM Tool

Lay Up

Autoclave & Final Part
Example

- Aircraft access door

Coordinated Tools & Parts

- Lay up mold defined by solid model
- Net shaped core defined by same model
- Trim & drill tool mastered to same solid model

Industry Partner:
Advanced Composite Structures
Coordinated Tool Family

Demonstrated Application

Application
• UAV wing box
• Light weight but high strength
• FDM Core provides interfaces for electronics

Coordinated Tool Family
• Male Lay Up Tool
• Female Co-Bond Tool
• FDM Consumable Core
• Trim Tool
• Drill Tool

Part CAD Model
Tooling CAD Models
Completed Cover
Male Lay Up Tool
Finished Part
Demonstrated Applications

- Core Material – SR30/SR100
- Epoxy resin systems
- Hand lay ups and fiber windings
- Vacuum bag, autoclave, & shrink wrap methods tested

Notes

- Core design should consider
  - Washout process
  - Thermal growth
- Cure temperatures
  - <250°F (121°C) ideal
  - 280°F (138°C) possible with special considerations
Hollow composite geometries
• Can be difficult to manufacture
• Complex geometries, complex tooling
• Require highly-skilled labor

Some available options
• Collapsible/inflatable cores
• Split-molds
• Soluble ceramics
• FDM soluble cores
A New Way to Manufacture

FDM Soluble Cores
- Robust, accurate cores
- Single-step manufacture
- Easy to use
- Digitally produced tooling
- Repeatable results
- New possibilities for complex geometries
## Material Properties

### Soluble Cores

<table>
<thead>
<tr>
<th>Property</th>
<th>SR30</th>
<th>SR100</th>
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<tbody>
<tr>
<td>Tg (°F)</td>
<td>212</td>
<td>271</td>
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<tr>
<td></td>
<td>(°C)</td>
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<tr>
<td>Ambient Tensile (KSI)</td>
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<tr>
<td></td>
<td>(Mpa)</td>
<td>41.4</td>
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<td>CTE (ASTM E228) 95°F-212°F</td>
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<td>5.5</td>
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<tr>
<td></td>
<td>[E-5 in/(in°F)]</td>
<td>[E-6 m/(m°C)]</td>
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<tr>
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<td>115.53</td>
<td>100</td>
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<tr>
<td>CTE (ASTM E228) 35°C-100°C</td>
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<tr>
<td></td>
<td>[E-5 in/(in°F)]</td>
<td>Available</td>
</tr>
<tr>
<td></td>
<td>Not</td>
<td>195</td>
</tr>
<tr>
<td></td>
<td>[E-6 m/(m°C)]</td>
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Preliminary Internal Testing
NIAR Results Pending

Third Party Independent Lab Testing
NIAR – National Institute For Aviation Research
Design Allowable - Soluble Cores

SR 100 Soluble Core Material
ASTM D6272 Dynamic Flex Test

3 Point bending flex test with temperature sweep through Tg of material

250°F Cure

Plan for 70% reduction in strength at 250°F cure temperature

Load (lb) Temperature (°F)

Fatigue Load: 60% of max

Temperature ramp rate: 17 °F/ min

Percent of Strength Reduction

SR100-Flat-1
SR100-Flat-2
SR100-Flat-3
SR100-End-1
SR100-End-2
SR100-End-3
Average
Design your core
- Create geometry in CAD
- Export STL

Process in Insight
- Determine part density
- Adjust raster air gap
- Set wall thickness
- Set “Invert build materials” checkbox
- Generate tool-paths
- Save and send to 3D printer
A Simple Process

Prep and seal the core
• Finish part as desired
• Seal with epoxy or mold sealer
• Apply release coat to core

Manufacture composite part
• Apply fiber material
  ─ Lay up prepreg or cloth
  ─ Wind fiber pattern
• Apply consolidation
  ─ Breather ply and cloth
  ─ Consolidation bagging
Cure composite part
  • Use appropriate oven temperature
  • Maintain consolidation pressure
Dissolve FDM soluble core
  • WaterWorks bath solution
  • Heated tank
  • Agitation circulation recommended
  • Rinse composite part
Large Wash Out Mandrel
Emerging Applications

Kazak Large Fiber Winding

- Large FDM core, 24” (61cm) diameter x 12” (30.5cm) tall
- Prepreg carbon fiber tow
- 200°F (121°C) Cure
- Integrated mandrel
  - Aluminum main shaft ~ 6’ (15.2cm) long x 9” (22.9cm) dia
  - FDM soluble core ends

Lessons Learned

- Design mandrel to support washout process
- If higher cure temperature is required, rotate part during cure
Turbo Inlet Pipes
Intake Plenum
Turbo Y Pipe
Intake Manifold
FDM Patterns / Molds
• Proper strength achieved with
  – ABS material
  – Double dense sparse fill interior
    – Reduces build time and material usage

Nevada Composite Tools
• Provide CTE matched tooling
• Two types of tooling solutions
  – Reusable
  – Soluble (dissolves in water)
• Tools support
  – Cure temperatures in excess of 370°C (700°F)
  – Pressures of 1,380kPa (200psi)
Composite Laminated FDM

- Net shaped core
- Composite laminated parts
- Epoxy resins & sheet adhesives readily bond to Ultem, PC, & ABS materials
- Lower temperature cure resins minimize CTE impacts

Plated FDM

- ABS & ULTEM are readily electroplated
- 10X plus - strength increase can be realized
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FDM Composite Material Considerations

Producing compounds
- Sensitivity to downstream processes

Producing filament
- Fibers or particles
- Interfacial modifiers
- Incorporation process and impact on fibers/particles

FDM Printing
- Shear effect on fiber sin extrudate
- layer to layer adhesion

Process environment interaction
- Support material interaction
- Build sheet interaction
Next Generation 3D Printing Composites
Stiffness vs. Heat Deflection Temp

Heat Deflection Temperature (HDT) at 66 psi [degrees F]

Uniaxial Tensile Modulus at Ambient [Mpsi]

Current portfolio
- PEKK
- CF-PA12
- CF-PES

Automotive Composites
- CF-PA6
- CF-PET

Aerospace Composites and Aluminum Replacement
- CF-PEKK

General Composites
Carbon fiber and PEKK together can offer some of the most impressive physical properties in both additive manufacturing and conventional processing. Early prototypes display not only good process compatibility, but also impressive physical properties.

- Strength over 150 MPa
- Modulus over 20 GPa
- Dimensional control and high HDT over 200 °C
“Functional” Composites

Thermally Conductive Materials
• Thermal conductivity up to 4 W/m-K in-plane as FDM output

Laser Direct Structuring (LDS) Materials
• Controlled activation of plating surfaces on parts of arbitrary geometry

Electrically Conductive Materials
• Resistivity <10^2 Ohm/sq

Particle-filled materials
• Metals, minerals, ferrites, glass beads/bubbles

Flame Retardant
• Amorphous or SC materials
Custom Fishing Lures!

http://store.romanmade.com/Roman_Made_Mother_p/mother.htm
Thank you!