Layup Tooling for Composites
Materials Selection
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Agenda

- Basics of Layup Tooling
- Layup Tooling Materials
- Material Sources
787 Layup Tooling

Wing Skin
- 110 ft x 23.5 ft
- Invar 36

Section 41 (Cab)
- 19 ft dia. x 48 ft.
- Carbon Fiber

Picture: Boeing Frontiers Online
Picture: Boeing.com
Mirabella 5

- Largest single-masted sailboat in the world
  - LOA 247 ft.
  - Beam 48.5 ft
  - 765 Metric Tons
  - Mast height 292 ft.
  - Builder: VT Shipbuilding

Pictures: Mirabella Yachts
Layup Tools – What They Do

- Layup and cure of production part
- Provide layup surface for composite part
  - Correct shape
  - Stable through cure cycle
  - Provide means of indexing part for next manufacturing operation
- Bad tools produce bad parts – important to get them right!

Nomenclature
- Layup Mandrels, Molds, Mold Dies, Bond Jigs, Bond Assembly Jigs, etc.
Layup Tools - Requirements

- Must be affordable
- Must be able to produce acceptable parts – pass NDI, dimensional inspection, cosmetic requirements
- Must have enough durability to meet planned production requirements
- Must maintain vacuum integrity
- Must properly react manufacturing loads
  - Autoclave, Tape layers, handling, debag/part removal, personnel, etc.
- Must not introduce contaminants into process
  - Outgassing, FOD, etc.
- Must be safe for layup technicians
  - No sharp edges, no trip hazards, etc.
Production Requirements
Drive Tooling Decisions

- How will the tool be used?
  - What processes are used? Hand layup or automation?
  - Used in an autoclave or in an oven?
  - At what pressure and temperature?
  - Used for single cure cycle or multiple cycles for bonding multiple details?
  - Used for co-cure or co-bond?

- What other tools are to be used in the production and assembly process?
  - Trim tools, stiffener indexing jigs, handling equipment, etc?

- If the decision is to use plastic tools, can the other tools use the same master model?

- How many tools do you need to make production rate?

- What are the cost targets?

- When is the tool needed?
Male Tooling vs. Female Tooling

For panels, female (OML-side) tooling is normally preferred
- Maintains aero quality
- Exceptions – fiber placing & filament winding
- Cauls required on male panel tools for smooth aero surface

For structure (Ribs Spars, Frames, etc), male tooling is normally preferred
- Generally produces best laminate quality
- Easier to remove parts

Exceptions exist:
- Female tools for structure provide best interfaces for assembly operations
  - Help minimize shimming due to uneven bag-side part surface
  - Rubber pressure intensifiers may be required for good laminate quality in female corners
Cure Temperature

Cure temperature may help you decide on tooling materials
- Low temp. cure with elevated post-cure?
- 250°F cure? (many non-structural applications)
- 350°F cure? (most commercial aircraft structural applications)

Coefficient of Thermal Expansion (CTE) of tooling materials vs. cure temperature vs. tool size
Thermal Growth of Tools

- Can you live with thermal growth?
- Cases where thermal growth is desirable
  - Provide additional pressure to laminate
- Cases where tool growth can cause problems
Approx. CTE of Common Tool Materials

Production Mat'ls (Gr/Ep)
Gr/BMI
Invar-36
Mono Graphite
Gr/Ep
Carbon Foam
Steel
Nickel
FG/Ep
Aluminum
Vantico Patty (LCTC)
Filled Epoxy
Ren Seamless
Paste
Last-A-Foam
Ren Shape 440
Effect of CTE

- Aluminum: 0.44 in.
- Fiberglass: 0.34 in.
- Steel: 0.23 in.
- Graphite/Epoxy: 0.07 in.
- Invar 36: 0.05 in.
- Graphite/BMI: 0.05 in.

Thermal growth of a 10 ft long tool RT (70º F) to 350º F (21º to 177º C)
Matching CTE with Parts

- Common practice is to closely match the tool CTE with the part material’s CTE.
- Especially true for big parts at high temperatures.
Using Dissimilar Materials in A Tool

- Dissimilar materials are frequently used in composite tools
  - Carbon Fiber face sheets
  - Tubular steel substructures
  - Bushings in working holes
- Attach points need to accommodate differences in thermal growth
- Generally not a good idea if tool dimensions exceed 6 feet.
Tooling Materials

Tooling material selection must consider several things:

- Cost
- Part size
- Cure temperatures
- Required longevity
- Availability of materials
- Capability of tool provider
- Quantity of rate tools
- What other tools are there in the “family?”
- Is a master tool available?
Cost of tools

Will expected return on investment justify the expense of durable tools?
Quantity of Rate Tools

- Rate tools are “additional copies” of your initial tool
- May be needed due to a number of things:
  - High demand for product
  - Part fabrication process takes a lot of time
- Sometimes it makes sense to validate the initial tool
  - Work out the bugs / make improvements
  - Incorporate the improvements into design, then make the rate tools
Required Longevity

- How many parts do you expect to build?
- Is there a chance that engineering will soon change?
- How big is your demand? Is there value in time to market?
  - Some less-durable tools can be produced much quicker than very durable ones
  - The more rate tools that you have, the less cycles that each might be used.
Availability of Materials

- Large increase in demand for Carbon Fiber
- Invar plate & billet lead times
- Invar casting lead times
- Invar cost escalation
 Capability of Tool Provider

Invar tools
- 5-axis machines & bed size
- Forming capability
- Heat treatment furnaces
- Hand working experience
- Material cutting
- Overhead handling of big tools
- Inspection capability
Capability of Tool Provider

Laminated Tools (CF/BMI, CF/Epoxy, etc)
- Machines & bed sizes
  - 5-axis, waterjet, etc.
  - Model machining or laminate machining
  - Willingness to machine carbon fiber
- Plastic/Plaster skills/ experience
- Oven or Autoclave availability
- Inspection capability
Capacity of Tool Provider

- What other work is ahead of your order?
- Can they deliver on-time?
- What’s their track record?
Tooling Material Selection Criteria

Tool material selection can be driven by a number of factors:

– Contour severity – tool producibility
– Costs – non-recurring (design & fab.) and recurring (repair & maintenance)
– Predicted durability – expected number of cycles
– Production rates and tool family requirements
– Thermal expansion of the materials – how much is too much?
– Size vs. CTE effects (“too much expansion” depends on how big the tool is)
– Cure temperature (“too much expansion” also depends on the cure temperature)
Contour Severity

- Severe contours can drive tooling material decisions
  - Cast Invar, Nickel, Composite materials
- How much panel flexibility and forgiveness is there?
- Will spring-back and warpage present problems?
- Producibility issues with formed metal tools:
  - Plate formability limits
  - Machinability (ability to reach into restricted areas with a cutter)

Picture: Torr Technologies

Picture: Mafix Inc.
Cost

- **Non-recurring costs**
  - Tool Design & Fabrication
  - Materials – factored into Tool Fabrication costs

- **Recurring costs**
  - Tool preparation
  - Tool repairs
  - Tool remake due to damage or failure

- **Cost of rate tooling**
  - Additional units of metal tools cost about the same as first unit
  - Composite tools – additional units should cost less
General Design Considerations

- Don’t want anything that might pierce or tear the vacuum bag
- Need to make the tool easy to use
- For multi-piece tools (e.g. for stiffeners), need to make tools or parts easy to remove without damaging parts or tools
- Resin can fill working holes
  - Best to have bushings in holes
- Tools and parts expand in the autoclave
  - Teflon pins – bent pins, ragged holes
  - Parts don’t always have the same CTE on heatup and cooldown
  - Lots of tool thermal growth = lots of internal stresses in parts, even if compensation factors are used
Tool Material Selection – Metal Tools

- Metal tools are most durable
  - They still can be scratched with knives and during debag!
- Metal Tools are generally most expensive
  - Little or no learning curve benefits for rate tools

Possible issues:
- Plate formability (may drive the use of castings)
  - Ability to reach surface with machine can drive male vs female decision
- Tool weight – composite tool would weigh substantially less
  - Some studies show composite tool would weigh 1/3 as much as Invar
Typical Tooling Materials – Production Programs

- Metals
  - Invar 36
  - Steel
  - Nickel
  - Aluminum

- Non-Metals
  - CF/BMI
  - CF/Epoxy
  - FG/Epoxy
Can you get the right sized billet of material to do a one-piece, non-welded tool?

Steel Tool face cut from single billet

Picture: Harvey, LTD; Manchester, UK

Picture: Process Fab, Inc.
Nickel Tooling

- Allows extreme contours
- Expensive
- Moderate CTE

Picture: Corima, Inc.

Picture: EMFCorp.
Invar 36

- (Primarily) Iron/Nickel alloy
- Low CTE alloy, invented in 1896
- Used as tooling material for composite parts since late 1980s
- Durable, predictable, few problems in use
- Not an exotic or hazardous material
- Other Invar alloys available – differing properties
- Can be obtained as castings
Fabrication Processes – (Most) Metal Tools

- Cutting of plate
- Welding
- Plate Forming
- Machining
- Heat Treatment (Annealing, Stress-Relieving)
- Hand Polishing
- Assembly
- Inspection
- Application of Release Agents

Picture: Waukesha Foundry, Inc.
Tool Material Selection - Composite LMs

Where do Composite LMs Make Sense?

- Where part geometry suggests/allows
- Where many units of tools are needed
- Where tool weight is an issue
- For relatively short runs
- For lower-temperature cures (250 degree cycles)
Composite LM Design – Unique Requirements

- Must design the tool similarly to design of composite parts
  - Ply table for face sheet or specify manufacturer’s ply schedule
  - Ply table for header boards (if making and not buying)
- Tool holes, inserts, threaded studs, etc. require skin padups
- Must protect tool from handling damage – rub strips, etc.
- If using honeycomb tooling board for headers, should pot or cover exposed honeycomb edges
- Potting of bushings
- Installation of hoist rings – backup plates
- Installation of metal structure – forklift channels, etc: consider differential CTEs
Limitations of Laminates

- Use as generous a radius as practical in corners
  - Avoid sharp corners – stress risers, poor laminate quality, etc.
- Use balanced laminate
  - Most tool laminates are quasi-isotropic
  - Follow recommendations of material suppliers whenever possible
  - Ask the material suppliers for recommendations where it’s not.
  - Don’t take shortcuts!
Composite Tooling Materials - Drawbacks

- Relatively soft – some production operations can erode tool surface
- Prone to inadvertent damage
  - Rough handling
  - Knives
  - Part removal
- Tool storage issues for some materials
- Higher recurring costs than for metal tools
Composite Tooling Materials – Advantages

- Rate tools can cost quite less than metal tools.
- Can do some shapes and contours that might be very difficult in metals.
- Huge benefits in lighter weight – can be 1/3 the weight of metal.
Gel Coated Composite Tools

Gel coats typically not used for aerospace composite tooling

- More appropriate for lower-temp applications
- Aircraft tooling typically uses prepregs that aren’t intended for use with gel coats.
Differences in Composite Tools - Substructure

Pic: The Fiberworks
Pic: Process Fab, Inc.
Pic: Janicki Industries
Pic: Burnham Composites
Composite Tooling
Life Expectancy

Examples of tool life from 10 to over 1000 cycles

Determinants of Life Expectancy
– Design practices
– Tool and Part Fabrication practices
– Cleaning and Tool Prep practices
– Tool Storage practices
– Tooling Materials used
Laminate Environmental Degradation

- Best predictor of laminate life is Glass Transition Temperature (Tg).
- Tg should always be higher than use temperature
- Laminates will absorb moisture – degrades Tg and mechanical properties
  - Exposure to rain & excessive humidity harmful
- Resins oxidize, microcrack – path for further lamina degradation
Composite Tooling
Material Suppliers

Advanced Composites Group (ACG) [www.acg-us.com](http://www.acg-us.com)
Airtech [www.airtechonline.com](http://www.airtechonline.com)
Axson [www.axson.com](http://www.axson.com)
Cytec [www.cytec.com](http://www.cytec.com)
Hexcel (Hextool) [www.hexcel.com](http://www.hexcel.com)
J.D. Lincoln [www.jdlincoln.com](http://www.jdlincoln.com)
Richmond Aircraft Products [www.richmondaircraft.com](http://www.richmondaircraft.com)
Others
Composite Tooling Materials – Substructure Components

Pictures courtesy of Burnham Composites except as noted

Pic: Airtech international
**Substructure Materials**

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<th>Laminate Panels</th>
<th>Honeycomb Panels</th>
<th>Round Tubes</th>
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<th>Angles</th>
<th>Tees</th>
<th>Columns</th>
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**Adv. Composites Group**
www.acg-us.com

**Airtech**
www.airtechonline.com

**Burnham Composites**
www.burnhamcomposites.com

Pic: Burnham Composites
<table>
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<th>Supplier</th>
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<tr>
<td>Re-Steel</td>
<td>Commerce City, CO</td>
<td>(800)</td>
<td><a href="http://www.re-steel.com">http://www.re-steel.com</a></td>
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<tr>
<td>Special Metals</td>
<td>Huntington, WV</td>
<td>(800) 334-4626</td>
<td><a href="http://www.specialmetals.com">http://www.specialmetals.com</a></td>
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Tool Fabricators

Good place to look for all things composite:

- Composites Sourcebook
  - [http://www.compositesworld.com/sb](http://www.compositesworld.com/sb)

- Categories
  - Tools
  - Mandrels
  - Materials & Supplies
  - Other
Questions or Comments?

For more info on this topic, contact Dave at dickson@thewiredcity.net

This webinar was brought to you by the members of the SME Composites Tech Group, part of the Plastics, Composites, and Coatings Technical Community of SME.

For more info contact techcommunities@sme.org

Thank you for attending!

Please plan to attend the next SME Composites Tech Group Webinar event on Tuesday, Sept.11, 2007 1:00-2:00 pm EDT!

“Managing and Monitoring Composites in the Supply Chain”