Advanced Composite Manufacturing for the Orion Program

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Why Composites?

Advantages

• Reduced structure weight - this is by far the biggest driver
  – Graphite/epoxy density is 40 percent less than aluminum
  – Actual weight savings depends on the application and number of joints but usually varies between 15% and 30%

• Reduced part count
  – Lower assembly costs

• Tailoring of material thickness is easy

• High corrosion resistance and fatigue capability
Why Composites?

Advantages

• Special advantages in special situations, e.g...
  – The use of low thermal conductivity glass/epoxy
  – The use of low thermal expansion material in satellites
  – The use of very high modulus material to minimize deflections
  – The use of low dielectric materials in radomes

• Tailoring of material properties is possible

• Wide variety of materials and forms to suit specific needs
Why Composites?

Disadvantages

• Larger scatter in material properties
• Sensitivity to manufacturing processes
• Complex analysis required
• Material cost
• Lack of material databases
• Sensitivity to moisture and elevated temperature
• Repairability
What are Composites?

- Composites are non-homogenous, reinforced, matrix bound materials that usually exhibit some desirable structural characteristics such as high strength, great stiffness, or low density.

- The reinforcing filaments may be boron, graphite, glass, etc., and the binding matrix is usually an epoxy, polyester, or polyamide resin, but may be a metal, ceramic, or glass.
History of Fibrous Composites

- Wood
- 800 B.C Straw and Mud Bricks (Adobe)
- 700 B.C Laminated Bow with Animal Tendons, wood, silk
- 1910 Doped Fabric and Wood A/C Structure
- 1935 Owens-Corning Fiberglass Corp.
- 1940 Plywood A/C Structure
- 1943 FRP Aircraft Structure
- 1947 First Commercial Epoxy
- 1953 Corvette FRP Production Body
- 1958 First Carbon from Rayon
- 1959 Texaco announces Boron
- 1961 First Graphite from Pan
- 1964 Carbon Fibers from Pan
- 1965 Boron Fibers Available
- 1969 F-4 Boron-Epoxy Rudder
- 1970 F-14 Boron/Epoxy Horizontal
- 1973 Kevlar 49
- 1985 Spectra
Current Applications of Composites

- Boat Hulls
- Ladder Rails
- Golf Club Shafts
- Skis
- Fishing Rods
- Tennis Racquets
- Auto Bumpers
- Boat Hulls
- Pipes
- Drink Bottles
- Space Shuttle
  - Payload Bay Doors
  - Nose Cap
  - Leading Edges
- Aircraft Radomes
- Aircraft Wings
- Bridge Structural Components
- Satellite Structures
  - Payload Bay Doors
  - Nose Cap
  - Leading Edges
- Pressure Vessels
- Antennas
- Hip Implants
Advanced Composites Manufacturing

• Focus on thermoset polymer matrix composites
• Focus on advanced composite structures
  – Resin matrix (epoxy, phenolic, bismaleimide, polyimide)
  – Reinforced with continuous fibers (carbon, glass, aramid, quartz)
  – Multiple plies with varying orientations
  – Used on highly loaded structures
  – High fiber to resin ratio (55-65% fiber by volume)
  – Low void content (<2% by volume)
  – Use temperature of 120°C or higher
Example Bagging Sequence for Cure

Vacuum bagging:
- Forms and consolidates the laminate
- Allows outgassing in the laminate during cure

1. Vacuum port*
2. Tool*
3. Edge dam
4. Laminate*
5. Peel ply
6. Release film*
7. Breather*
8. Nylon vacuum bag*
9. Sealant tape*

* needed for debulks
Manufacturing Methods

• Manual methods
  – Hand layup
  – Resin infusion methods
    – Resin transfer molding (RTM)
    – Vacuum assisted resin transfer molding (VARTM)
    – Resin film infusion (RFI)

• Automated methods
  – Filament winding
  – Automated tape laying
  – Advanced fiber placement
Hand Layup

• Process Description
  – Hand place reinforcement onto tool
  – Vacuum bag layup
  – Oven or autoclave cure

• 2 Basic Methods
  – Prepreg lay up - unitape and fabric
  – Wet lay up
    – Lay down dry fabric, pour or brush resin into the fabric
    – Pre-wet dry fabric then lay up on mold
Hand Layup

• Consolidation Methods
  – Intermediate debulks during layup
  – External pressure (vacuum bag or autoclave) during cure

• Tooling
  – Composite, Invar, aluminum, steel
  – Must be able to withstand cure temperatures and pressures
Hand Layup

• Application Considerations
  – Material compatibility - unlimited combination of fiber and resin
  – Part geometry - complex parts, small to moderate size
  – Equipment requirements - oven or autoclave
  – Material scrap - high
  – Labor cost - high
  – Material lay down rates - low
  – Repeatability - low
    – Improved with automated ply cutters and laser ply projection systems
  – Good process for small part size, small number of units, and parts with complex shapes
Hand Lay Disadvantages

Fabricating prepreg laminate structures* can be accomplished many ways:

- Hand operations
  - Typically limited to fabric
  - Used extensively in prototype and small to medium size parts
  - Several advantages
    - No capital investment in equipment
    - Simpler less expensive setup and operation
    - Can do complex contoured surfaces
  - Several disadvantages
    - Limited through put/productivity
    - Quality issues
      - Limited accuracy/repeatability
      - Human error
    - High material scrap factors
      - Materials remaining after pattern nesting and cutting

* This does not consider dry fiber fabrication processes such as filament winding and resin infusion
Advanced Fiber Placement

• Process Description
  – Automated machine places multiple unitape prepreg tows on mandrel
  – Placement up to 32 tows, tows are usually 1/8” wide
  – Tows can be added, dropped, and added again at any time during the lay down process
  – Vacuum bag layup to the tool
  – Oven or autoclave cure

• Consolidation Methods
  – Compaction by applying pressure and heat at roller in placement head
  – Intermediate debulks during layup
  – External pressure (vacuum bag or autoclave) during cure
Advanced Fiber Placement

rotating mandrel

multi-axis fiber placement head
Advanced Fiber Placement

• Tooling
  – Composite, Invar, aluminum, steel
  – Must withstand head pressure, cure temperatures, and cure pressures

• Application Considerations
  – Material compatibility - unitape only
  – Part geometry - moderate to large parts with complex contours
  – Equipment requirements - fiber placement machine, autoclave
  – Material scrap - low
  – Labor cost - low
  – Material lay down rates - high
  – Repeatability - high
  – Good process for large parts with complex surfaces
Fabricating prepreg laminate structures* can be accomplished many ways:
- Automated operations
  - Fiber placement
    - Process originated from tape laying
    - Places multiple “tows” of narrow unidirectional prepreg tape on a tool surface typically in quasi-isotropic ply build ups (0°, +/- 45° and 90° fiber orientations)
- Several advantages
  - High productivity (high lbs./hr. lay down rates)
  - High accuracy/repeatability
  - Can lay on relatively complex curved tool surfaces
  - Cutting and adding tape has a very low scrap factor
    - Narrow 1/8” tows create very fine saw tooth pattern for near net shape ply boundaries
- Disadvantage
  - Capital investment
Why Fiber Placement

Process diagram:

- Individual 1/8” unidirectional prepreg carbon fiber “tows”
  (typically 12, 24 and 32 tow configurations)
- Individual tow clamps
- Individual tow cutters
- Individual feed and add rollers
- Compaction roller
- Heater nozzle (discharges heated nitrogen)
- Direction of feed
- Tool surface
- Course of individual tows
Orion Composites

- Fiber Placement chosen as primary composite manufacturing process on Orion
- Composites consist of greater than 30% of primary structure (~130 parts/vehicle)