Summary of Methods used to Manufacture PMCs
Preliminary Manufacturing Considerations

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• Steps taken to achieve these goals typically increase material and manufacturing costs…
Preliminary Manufacturing Considerations

- Composite manufacturing process(es) selected for use often depends on the premium the customer is willing to pay for reduced variability (and therefore for lighter weight and/or improved properties)

Reinell Runabout

Americas Cup Racing Yacht
Preliminary Manufacturing Consideration

A basic decision...does the manufacturer of a composite part:
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- ‘Preimpregnate’ the fiber with resin, forming an intermediate product called ‘pre-preg’. Composite part then produced in a subsequent manufacturing process using pre-preg as the ‘raw’ material...known as a ‘dry’ process. In general: the use of prepreg reduces material variability but increases costs.
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  ....OR....

- Combine fiber and liquid resin matrix while simultaneously producing the (final) composite part....known as ‘wet’ manufacturing processes. In general: wet processes result in increased material variability but are relatively inexpensive.
Another basic decision is the physical form of the fiber reinforcement...fibers are available as:
  • Discontinuous (chopped) fibers
  • Roving spools
  • Mat fabrics
  • Unidirectional plies (layers)
  • Woven or braided fabrics

Reinforcements in any of these forms (or some combination thereof) can be used in either pre-preg (“dry”) or wet manufacturing processes.
Summary of Manufacturing Methods

Following discussion divided into two categories

- Prepreg based processes (“dry”)
- Non-prepreg based processes (“wet”)

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Prepreg Manufacturing
Thermoset (Epoxy) Resin Mix

- Epoxy Base Resin
- Accelerator (Promoter) • Heat Activated
- Inhibitor • Slows down Reaction at Low Temp. • Provides Longer Outtime • Heat Deactivated
- Additives • Tougheners • Fire Retardant • Smoke Inhibitor

“A” staged resin

- Hardener (Curing agent)
- Reduce Viscosity for Ease of Flow Into Fiber Bed
- Solvent Impregnation Process
- Hot Melt Impregnation Process
Prepreg Manufacturing
Solvent Impregnation

Dry Fabric Roll

B Staging

Work compaction rolls

Prepreg take up

Low Viscosity Resin/Solvent Solution

Tower or horizontal oven

Fiber Creel

(Or)

B-Staged Fabric Prepreg

B-Staged UD Tape Prepreg

Bag & Freeze
The ME Department walk-in freezer is used to store prepregs, thin-film adhesives, etc, and maintains a temperature of -18°C (0°F)
Prepreg Manufacturing
Hot Melt Impregnation

Prepreg takeup

Fiber Creel

Dry Fabric Roll

Resin film (on/off line)

Hot plate

Chill plate

Slitter

Hot compaction rollers

Paper takeup

Bag & Freeze

B-Staged UD Tape

Prepreg

B-Staged Fabric

Prepreg
Hot Melt Fiber Impregnation

Matrix resin film

Dry Form of Fiber (Fabric or Tow)

Matrix resin film

Heated Plate

Chill Plate

Heat & Pressure

Prepreg

Resin Viscosity
The ME Department walk-in freezer is used to store prepregs, thin-film adhesives, etc, and maintains a temperature of -18°C (0°F)
Prepreg Manufacturing
Creel Setup – Unidirectional Tape

To Prepreg Line
Prepreg Material Forms

Unidirectional

UD Tape
- Automated equipment
- Higher laydown rates
- Fiber orientation tailorable
- Good material usage
- Limited contour use

Slit Tape
- AFP (Automated Fiber Placement) equipment
- Low laydown rates
- Fiber orientation very tailorable
- Excellent material usage (Buy to Fly Ratio)
- Better for Compound contour
Prepreg Material Forms

Woven Fabric

Woven fabric

• Drapability good
• Fiber orientation less tailorable (0/90, +/-45)
• Poor material usage (buy-to-fly ratio)
• Mostly used for hand lay up of H/C sandwich structures
General Prepreg-Based Manufacturing Flow

1. Cold storage (0°F) In Sealed Bag
2. Cutting Plies At Room Temp.
3. Panel layup
   - Composite Prepreg plies
   - Adhesive
   - H/C core
4. Tool prep and bag
5. Autoclave Curing
6. Trimming, inspection, and assembly
Creating the Laminate Stack

• Hand layup processes
  – Plies cut from parent prepreg role to desired shape, either
    • Manually or
    • With NC-controlled ultrasonic knife (minimizes edge fraying)
  – In hand-layup plies are usually woven or braided fabrics, but can be unidirectional tape
  – Hand layup often involves ply kits:
    • Plies cut from prepreg
    • Stack sequentially in intended laminate
    • Sealed in air-tight bag and returned to freezer to retain tack
    • Efficient production flow

• Automated (computer-controlled) layup processes
  – Mostly involve UD tape, but can also be used with fabric
  – NC controlled cutting during automated layup of each course directly on tool
  – Sometimes combined with hand layup
Hand Layup

• Hand layup implies
  – Hand placement of precut plies
  – Very flexible
  – Low capital investment
  – Labor intensive
  – Can involve safety issues/repetitive trauma

• Applications
  – Used on most secondary structure in aerospace composites
  – Not used for very large parts
Hand Layup

Producing “precut plies” from parent roll

• Pre-preg can be to desired shape by hand (i.e., using a razor blade, utility knife, etc), but

• Various types of computer-controlled cutters available and are far more precise and convenient
Automated (Computer-Controlled) Layup Processes

- Three major categories, in chronological order of development:
  - NC Filament winding (bodies of revolution)
  - Automated Tape Laying machines
    - Flat tape laying machines
    - Contoured Tape Laying Machine
  - Automated Fiber Placement (AFP) machines (a hybrid of filament winding and automated tape laying machines)
Filament Winding

- Used for decades (computer-controlled winders developed in 70’s)
- High lay-down rates (400 lbs/hr)
- Either pre-preg or wet winding
- Bodies of revolution only (can’t wind concave surface)

http://compositetechnology.blogspot.com
Automated Tape Laying Machines
(http://www.automateddynamics.com/gallery/)
Automated Tape Laying Machines

ATLP machines available that dispense 1”, 3”, 6”, or 12” UD pre-preg

Can produce parts with modest curvatures
Automated Fiber Placement Machines
(http://www.automateddynamics.com/gallery/)
Automated Fiber Placement Machines
(http://www.electroimpact.com/)

Boeing 787 fuselage barrel sections produced using an automated fiber placement machine designed/built by Electroimpact (Mukilteo, WA)
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Vacuum Bagging

Indexing Holes (2)

Net Trim Line

Release Coating/Film

Generic Composite Tool
Vacuum Bagging

- Composite Laminate
- Vacuum Bag
- Surface Breather
- Optional Caul Plate
- Tool
- Edge Breather
- Edge Sealant
- Release Film
- Vacuum
General Prepreg-Based Manufacturing Flow

Cold storage (0°C F) In Sealed Bag

Cutting Plies At Room Temp.

Panel layup
- Composite Prepreg plies
- Adhesive
- H/C core

Tool prep and bag

Autoclave Curing

Trimming, inspection, and assembly
Autoclave Cure

• An autoclave is a heated pressure vessel that allows
  – Vacuum to be drawn in interior region(s)
  – Heatup and cooldown rates to be precisely controlled
  – Internal pressure applied using inert gas (usually N₂, rarely air)

• Autoclave sizes vary widely
• Most structures produced using pre-preg are cured using an autoclave (some exceptions)
Typical Autoclave Features
(up to 700F and 300 psi)

• Thermocouples:
  – Fixed TC (permanent, controls power input)
  – Part TCs (disposable, monitor local heat-up and cool-down rates)

• Electric, gas, or steam heat
• Chilled water (or occasionally oil) cooling system
• Internal fan to circulate pressurizing gas (air, N₂, or CO₂) and minimize thermal gradients
Summary of Manufacturing Methods

Following discussion divided into two categories

• Prepreg based processes (“dry”)
• Non-prepreg based processes (“wet”)
Wet Hand Layup
Lowest Cost/Highest Variability

1. Hand place dry fibers
(usually glass or carbon fabric)

2. Apply low viscosity resin
(pour, brush or spray)

3. Wet out/remove air
(squeegee, roller or vacuum bag)

4. Cure:
- Room temp w/o vacuum bag,
- Room temp w/vacuum,
- Vacuum bag w/oven
- Vacuum bag w/autoclave
Chopped Fiber Spray-Up

- Roving
- Roving Cutter
- Flexible Hose
- Turntable
- Air Exhaust
- Blower
- Preform Screen
- Binder Spray
Chopped Fiber Spray-Up

- Can produce complex shapes, and medium-to-large parts
- Continuous fiber fed, chopped (1-3“), and combined/sprayed with catalyzed resin
- Laminate densified and air removed manually (rollers, squeegeies) or with vacuum bag
Chopped Fiber Spray-Up

- A highly automated (computer-controlled) version of fiber spray-up, called the Programmable Powdered Preform Process (P4), is used to produce lightweight automobile and truck parts.

Applicator P4 gun developed by Aplicator System AB (Sweden)

P4-SRIM truck bed and tailgate on 2001 Chevy Silverado is 50 lb and 15 lbf lighter, respectively, than steel counterparts.
Resin Infusion

with low temperature cure resins

Room temperature to 90°C

Vacuum pump

Resin

Vacuum bag sealant tape AT 200 Y

Fittings

Polyethylene tubing (outside the bag)

Resin feed line

Vacuum tubing

Resin trap

Vacuum reservoir - RB451

Fittings

Polyethylene L-Fittings

Mould

Toolmaster® Prepregs or Toolmaster® Laminating resins or Toolfusion® 1 or 2 Resin

Resin flow media

Greenflow 75

Pressure sensitive tape

Econobreaker

Resin flow lines

OF 313 / PE tubing (under the bag)

Vacuum bag Econolon

Fabric reinforcement

Carbon or fiberglass trailing cloth

www.airtech.lu/site/medias/_pdf/france/procedeEN.pdf
Resin Infusion

*with low temperature cure resins*
Resin Infusion avoids the need for very large autoclaves

http://www.tygavac.co.uk/markets/wind-energy.html

(www.rnp.org/Projects/stateline.html)
Compression Molding

- Placement of Charge
- Mold Closure
- Cure Under Heat and Pressure (or consolidate if TP)
- Demold
Compression Molding
widely used to produce auto/truck parts
Compression Molding
prototype HexMC aircraft window frames
Injection Molding

• Base and frame of K2 inline skates produced using injection molding and short fiber glass/PP and glass/nylon composites
Pultrusion

- High-volume process
- Constant cross-section
- Can use either resin bath or pre-preg
- Can use either thermoset or thermoplastic
Pultrusion
Hybrid manufacturing processes

- K2 downhill skis and snowboards produced using
  - Wood core (fir, aspen, bamboo...)
  - Several plies, including
    - Short glass fiber mat
    - Stitched unidirectional glass and carbon plies
    - Continuous glass fiber triaxial overbraid
  - Wet layup epoxy with amine curing agent
Overbraiding of wood core and short-fiber glass mat
Overbraiding of wood core and short-fiber glass mat
Unidirectional Glass Fabric
Preparing for Impregnation w/Wet Epoxy Resin
Compression and Heat Used to Consolidate and Cure Composite
Finished Product