Introduction to Composites

Professor Robert Sadler
Center for Composite Materials Research
North Carolina A&T State University
Greensboro, NC 27411

What is a composite?

A material consisting of two or more distinct materials which retain their identity when combined together provide properties unobtainable with either constituent separately

History of Composites

- Nature

  Uses composites in structure components of both animal and plants.
- Man

  Ancient civilizations made bricks of mud and straw.

  Mongols made bows of cattle tendons,wood and silk.

  Japanese samurai swords and Damascus gun barrels were both made of layers of iron and steel.

Composites as Unique Materials

- Specific tensile strength can be 4 to 6 times greater than steel or aluminum.
- Specific modulus can be 3 to 5 times that of steel or aluminum.
- Specific thermal conductivity can be 40 times than that of copper.
- Fatigue resistance greater than steel or aluminum.
- Provides greater design flexibility than homogeneous materials.
- Potential for corrosion reduced significantly.
- Part count can be minimized and fastening methods simplified.

Composite Applications

- Aircraft components
- Sports equipment
- Marine structures
- Transportation components
- Construction forms and components
- Electrical equipment
- Tooling for manufacturing
- Medical equipment and body components
- Metrology equipment

Material Properties

Material	Specific G	Modulus	Strength	CTE
Steel	7.8	30 Msi	57 Ksi	6 X 10^{-6}/F
Aluminum	2.8	10.4	60	13
Carbon Fiber	1.8	34	540	-1.1
Glass Fiber	2.5	10.5	500	2.9
Carbon/ Epoxy	1.6	20.6	330	-0.5

Primary Composites Based on Thermosetting Matrix

- Polyester/Glass
- Vinyl Ester/Glass
- Vinyl Ester/Carbon
- Epoxy/Glass
- Epoxy/Carbon
- Epoxy/Aramid
- Bismaleimide/Carbon
- Polyimide/Carbon
- Cyanate Ester/Carbon
- Carbon/Carbon

Relative Cost of Raw Materials

(Dollars/Pound)

- Polyester 1
- Vinyl Ester 4
- Epoxy 7
- Cyanate Ester 80
- Bismaleimide 100
- Polyimide 100

- Glass Fiber 1
- Carbon Fiber 30
- Aramid 25

- Prepregs
  Epoxy/Carbon 60
  Bismaleimide/Carbon 200

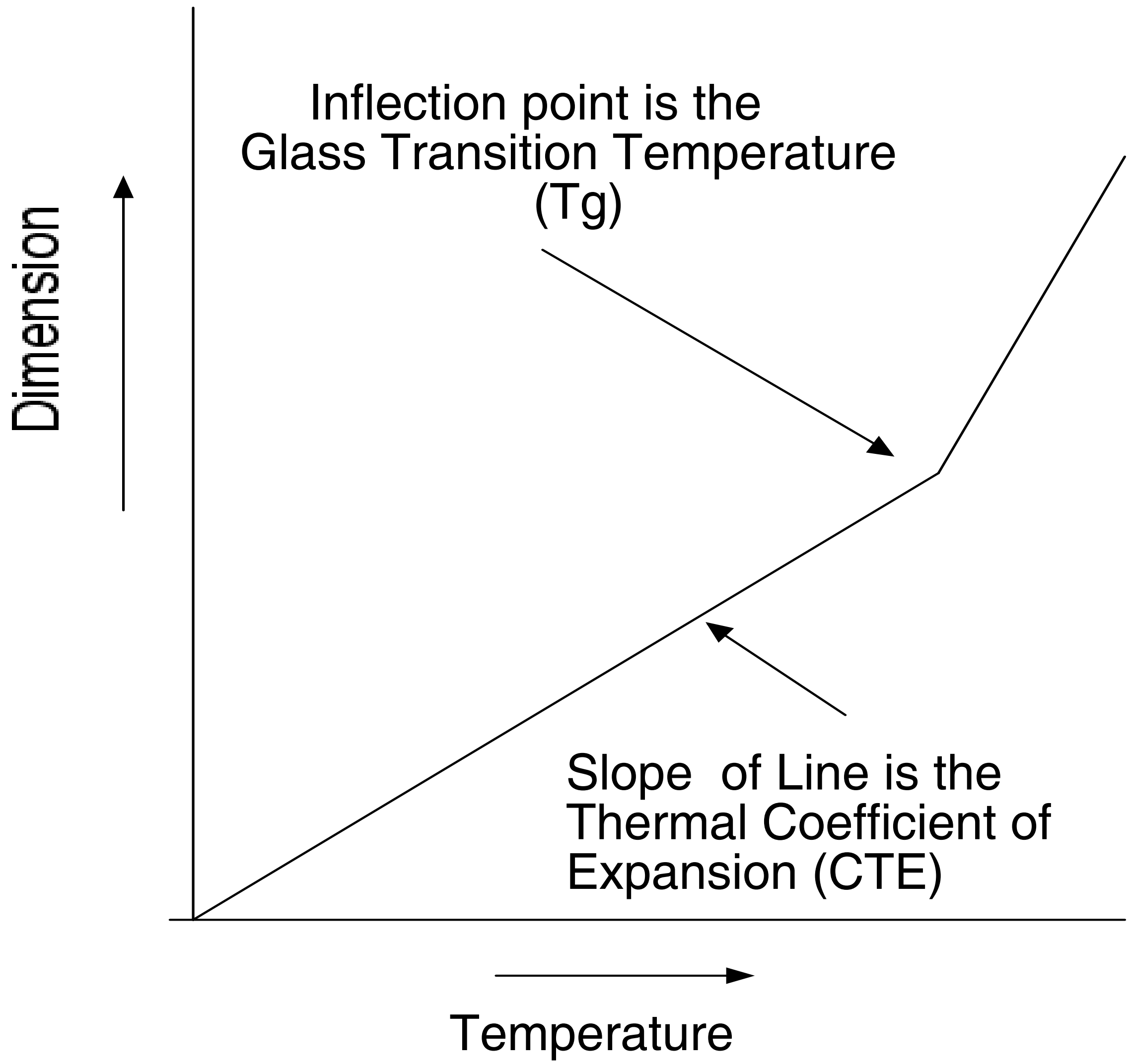
Matrix Temperature Resistance

• Polyester	200 F
• Vinyl Ester	250 F
• Epoxy	350 F
• Bismaleimide	500 F
• Polyimide	550 F
• Cyanate Ester	650 F
• Carbon	5000 F

Polyester/Glass Composites

- Advantages
  - Low cost raw materials
  - Low cost tooling
  - Easy fabrication
  - Many production processes
  - Durable
  - Good finishes
- Disadvantages
  - High matrix shrinkage
  - Exotherm must be managed
  - High specific gravity
  - Relatively low modulus
  - Low Glass transition temperature (Tg) < 200 F

Thermal Mechanical Analysis



Vinyl Ester/Glass Composites

- Advantages
  - Relatively low cost
  - Easy fabrication
  - Many fabrication processes
  - Durable
  - Good finishes possible

- Disadvantages
  - High shrinkage
  - High specific gravity
  - Relative low modulus
  - Low Glass transition temperature < 250 F

Epoxy/Glass Composites

- Advantages
  - Excellent Electrical Properties
  - Good Mechanical Properties
  - Many production processes
  - Low Shrinkage During Polymerization
  - Glass Transition Temperature (Tg) < 350 F
  - Durable

- Disadvantages
  - Moisture Absorption
  - Limited Geometric Configurations
  - High specific gravity

Epoxy/Carbon Composites

- Advantages
  - Excellent Mechanical Properties
  - Excellent Fatigue Properties
  - Low Specific Gravity
  - Low Thermal Coefficient of Expansion
  - Low Shrinkage During Polymerization
  - Glass Transition Temperature (Tg) < 350 F
  - Good Durability
- Disadvantages
  - High Material Cost
  - High Fabrication Cost

Bismaleimide/Carbon Composites

- Advantages
  - Excellent Mechanical Properties
  - Excellent Fatigue Properties
  - Low Specific Gravity
  - Low Thermal Coefficient of Expansion
  - Low Shrinkage During Polymerization
  - Glass Transition Temperature (Tg) < 550 F
  - Good Durability
- Disadvantages
  - High Material Cost
  - Very High Fabrication Cost

Polyimide /Carbon Composites

- Advantages
  - Excellent Mechanical Properties
  - Excellent Fatigue Properties
  - Low Specific Gravity
  - Low Thermal Coefficient of Expansion
  - Low Shrinkage During Polymerization
  - Glass Transition Temperature (Tg) < 600 F
  - Good Durability
- Disadvantages
  - High Material Cost
  - Very High Fabrication Cost
  - Condensation Reaction During Cure
  - Carcinogen During Processing (methylene dianiline)

Cyanate Ester /Carbon Composites

- Advantages
  - Excellent Mechanical Properties
  - Excellent Fatigue Properties
  - Low Specific Gravity
  - Low Thermal Coefficient of Expansion
  - Low Shrinkage During Polymerization
  - Glass Transition Temperature (Tg) < 650 F
  - Good Durability
  - High Char Yield
- Disadvantages
  - High Material Cost
  - High Fabrication Cost

Carbon /Carbon Composites

- Advantages
  - Good Mechanical Properties
  - Low Specific Gravity
  - Low Thermal Coefficient of Expansion
  - Very High Temperature Resistance (~ 5000 F)
  - High Specific Thermal Conductivity (40 X that of Cu)
- Disadvantages
  - High Material Cost
  - Very Long Processing Times
  - Very High Fabrication Cost

Major Composite Processes

- Hand Layup
- Vacuum Bag
- Vacuum Assisted Resin Transfer Molding
- Resin Transfer Molding
- Resin Infusion
- Compression Molding
- Autoclave
- Pultrusion
- Filament Winding

Fabricating Composites by Hand Layup

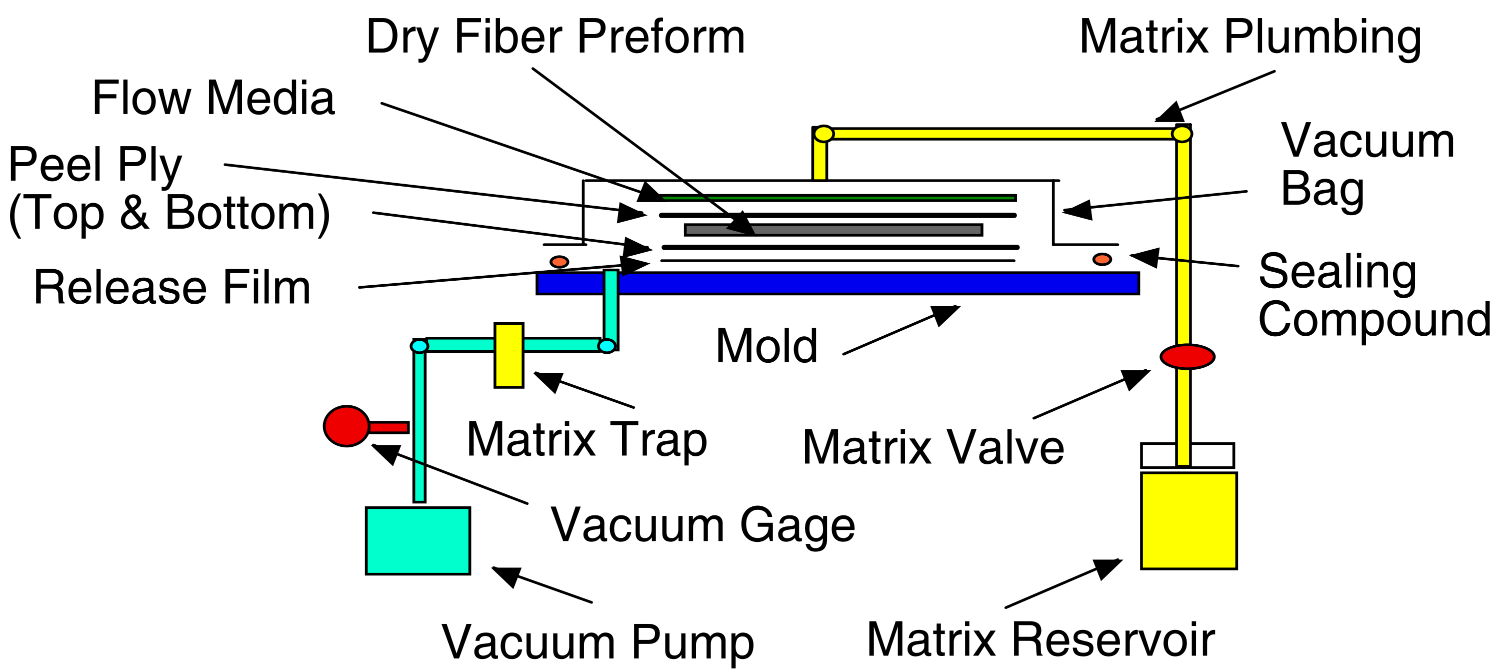
- Advantages
  - Very Low Cost for Low Volume Production
  - Simple Low Cost Tooling
  - Low Skill-Level Required
  - Low Cost Materials (Usually Polyester & Glass)
  - Very Large Parts Practical
- Disadvantages
  - Quality is Variable
  - Modest Mechanical Properties
  - Serious Environmental Concerns
  - Only One Good Surface

Fabricating Composites by Vacuum Bag

- Advantages
  - Relatively Low Cost for Low Volume Production
  - Simple Low Cost Tooling
  - Higher Fiber Volume than Hand Layup
  - Low Cost Raw Materials (Polyester & Glass)
  - Very Large Parts Practical
  - Quality Less Variable than Hand Layup
  - Reduced Environmental Concerns
- Disadvantages
  - Only One Good Surface
  - Generates Trash

Fabricating Composites by VARTM
(Vacuum Assisted Resin Transfer Molding)

- Advantages
  - Relatively Low Cost for Low Volume Production
  - Simple Low Cost Tooling
  - Higher Fiber Volume than Vacuum Bag
  - Low Cost Materials
  - Very Large Parts are Practical
  - Reduced Environmental Concerns
  - Quality Less Variable than Vacuum Bag
- Disadvantages
  - Only One Good Side
  - Generates Trash
  - Cost of Bagging Materials



Setup for VARTM

(Vacuum Assisted Resin Transfer Molding)

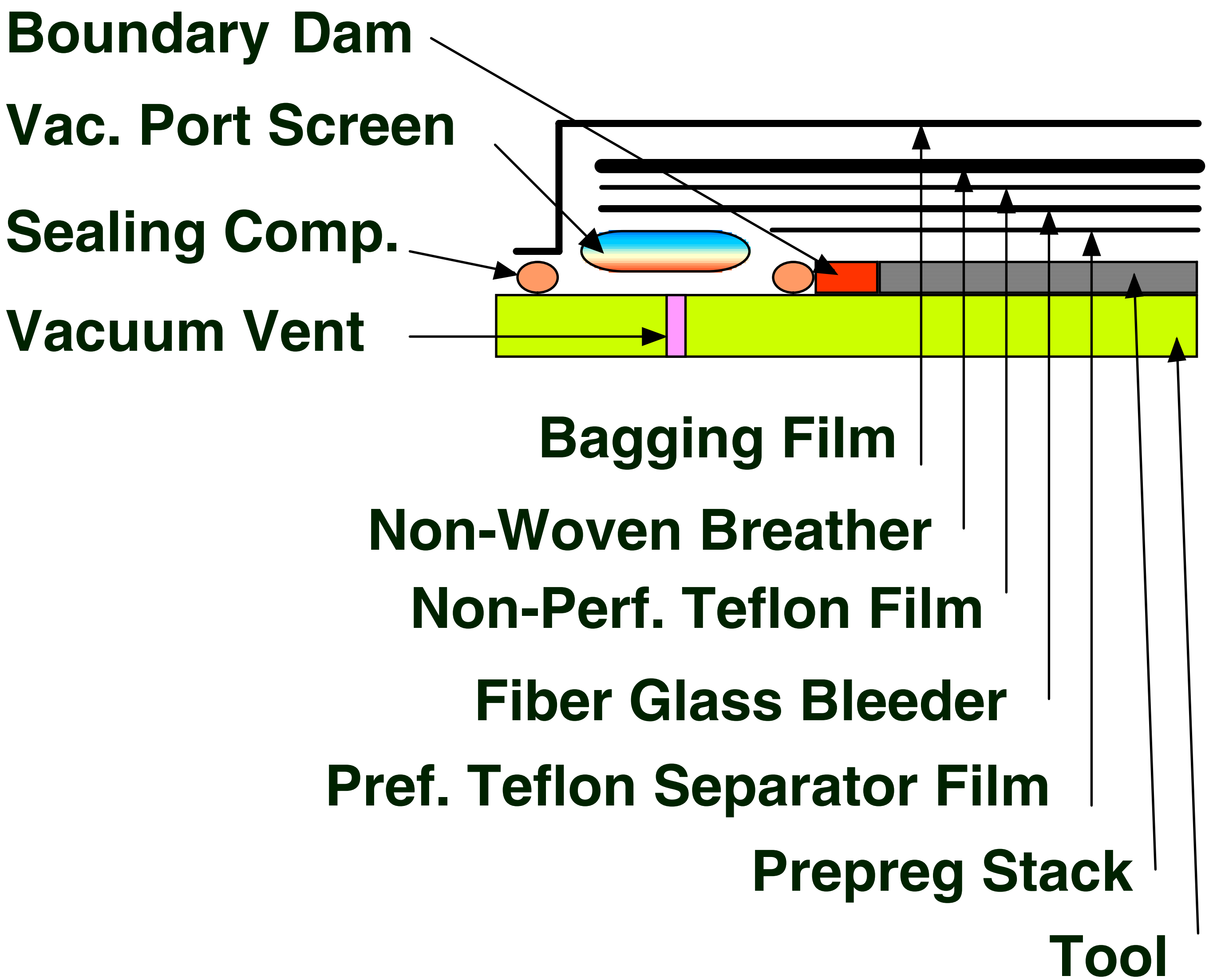
Fabricating Composites by Compression Molding

- Advantages
  - Low Cost for High Volume Production
  - Good Mechanical Properties
  - High Fiber Volume Practical
  - Close Dimensional Tolerances Possible
  - Mold Finish on Both Sides
  - Good Quality Control
- Disadvantages
  - High Tooling Cost
  - Compression Press Required
  - Part Size Limited to Press Size
  - Heat Source Required

Fabricating Composites by Autoclave Molding

- Advantages
  - Excellent Mechanical Properties Possible
  - High Fiber Volume
  - Low Cost Tooling Possible
  - Excellent Quality Control Possible
- Disadvantages
  - Must have Autoclave (Very Expensive)
  - Expensive Raw Materials (Prepreg)
  - Requires Large Quantities of Utilities
    - (Electricity, Water & Compressed Gas)
  - Generates Trash

Bagging for Autoclave Cure



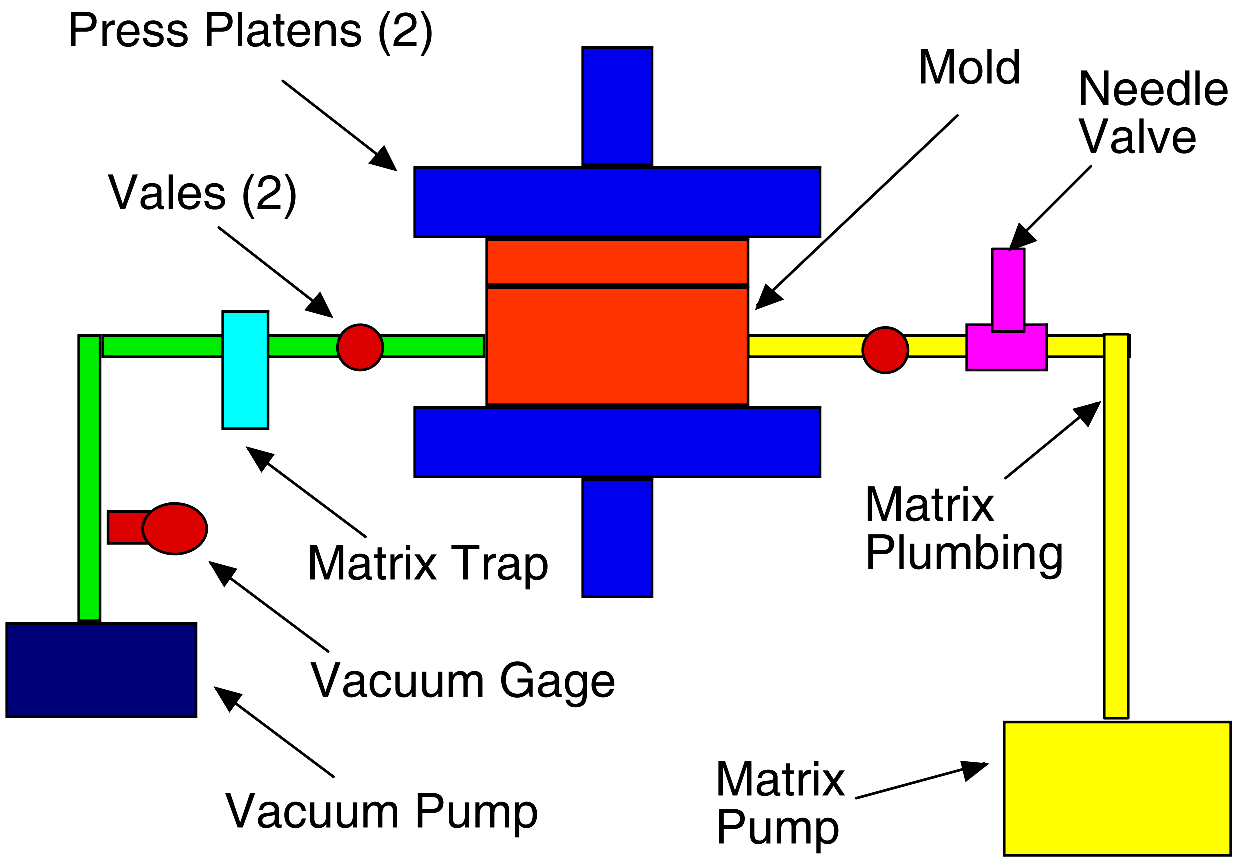
Fabricating Composites by Filament Winding

- Advantages
  - Excellent Mechanical Properties
  - Can Utilize Low Cost Materials
  - Low Cost Tooling Possible
  - Low Hands-On Labor Cost
- Disadvantages
  - High Cost Equipment Required
  - Limited to Parts with a Surface of Revolution
  - Only One Good Surface Possible

Fabricating Composites by RTM
(Resin Transfer Molding)

- Advantages
  - Excellent Mechanical Properties
  - High Fiber Volume
  - Relatively Low Capital Equipment Cost
  - Relatively Low Cost Raw Materials
  - Complex Geometric Parts Possible
  - Excellent Quality Control Possible
  - Near-Net Shape Parts Possible
  - Close Dimensional Tolerances Possible
  - Mold Finish Over Entire Part
- Disadvantages
  - High Tooling Cost
  - Mold Deflection During Processing

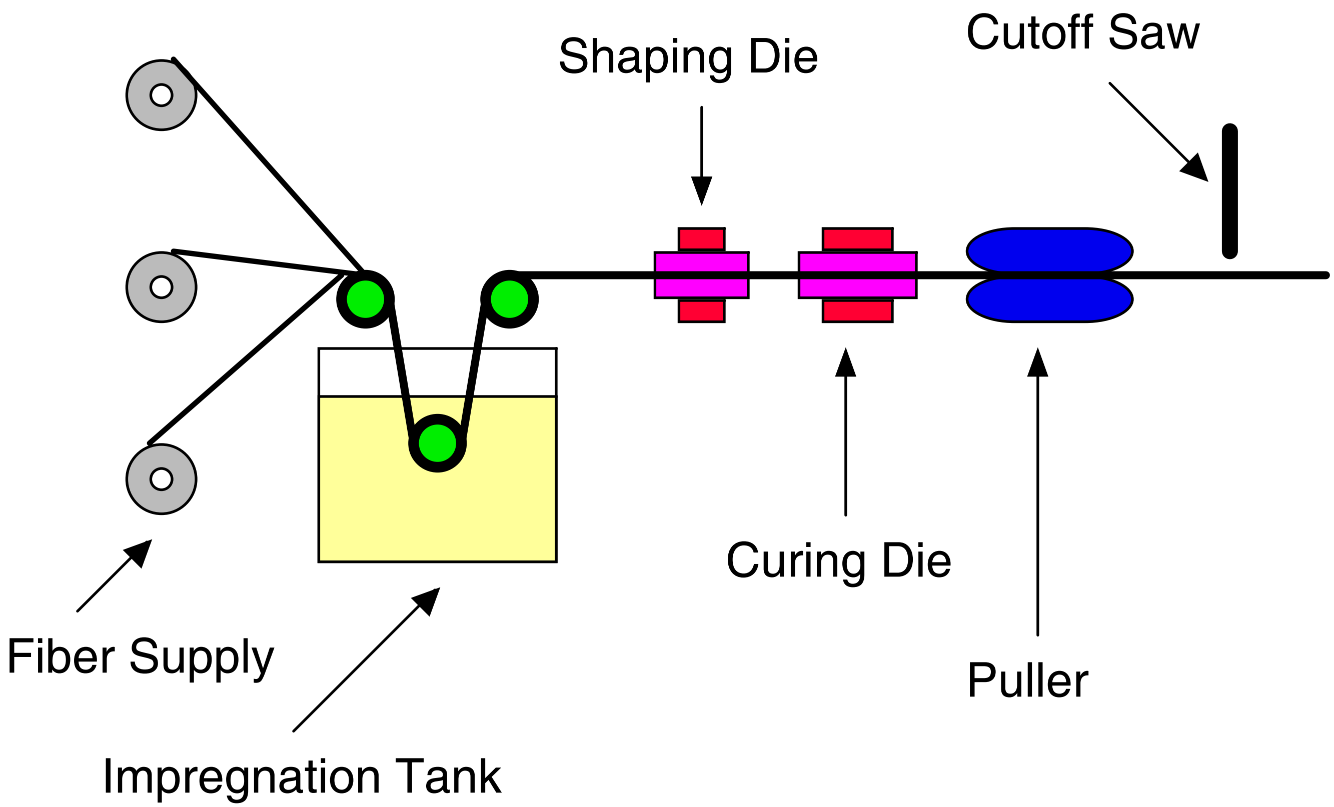
RTM with Epoxy



Fabricating Composites by Pultrusion

- Advantages
  - Good Mechanical Properties
  - Low Cost Raw Materials
  - Low Cost Tooling
  - High Production Rate

- Disadvantages
  - Limited to Parts with a Constant Cross-section
  - High Cost Equipment Required
  - High Start-up Cost
  - Can Only be Justified for Large Production Runs



Pultrusion Setup

Future Composite Applications

- Additional Aircraft Components
- Human Body Structural Components
- Precision Dimensional Measurements Devices
- Concrete Reinforcement in Buildings
- Bridge Construction Components
- Automotive Body Components
- Components for Internal Combustion Engines
- Utility Poles
- Production Tooling