# MAE 661 Laminated Composites

## Introduction

## Materials and Processes

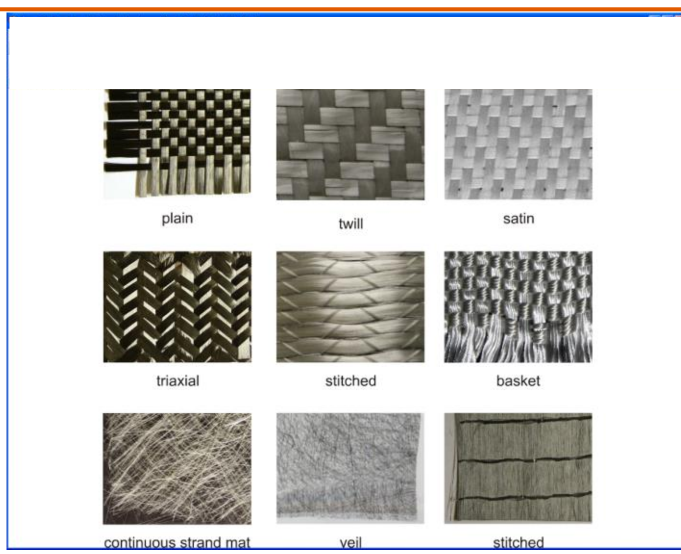
## Fibers

- Glass Fibers
- Carbon Fibers
- Organic fibers
  - Aramid, e.g. Kevlar
- Others (less common)
  - Silica and quartz
  - Carbon nanotubes
  - Boron
  - Ceramic (e.g. SiC)
  - Metals

# Fiber Forms

- Continuous fibers
  - Threads (1-D textiles, fiber bundles)
    - Strand, tow, end, yarn, roving
  - Fabrics (2-D textiles)
    - Woven as a planar cloth
    - Various weave patterns: plain, twill, satin
    - Random orientation: continuous strand mat
  - 3-D textiles
    - 3-D weaves, braiding, knitting
- Discontinuous fibers (chopped, whiskers)

# 2-D Fiber Forms



# Matrix Materials

- Polymer matrix (most common)
  - Thermoset resins: cure process involves irreversible crosslinking
    - Examples:
      - Polyester: low cost
      - Vinyl ester: intermediate cost/performance
      - Epoxy: higher cost/performance
      - Phenolic: low flammability and smoke production
    - Finite pot life extended by refrigeration
    - Cure time can be shortened by elevated temperature
  - Thermoplastics: no chemical change during processing
    - Heated to softening temperature for processing
    - Can be reheated/re-processed
    - Processing is more difficult than thermosets
    - PEEK is commonly used for high performance applications

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# Additional Considerations

- Polymers are viscoelastic: properties are time (rate) and temperature dependent
  - Subject to creep and stress relaxation
  - Addition of reinforcements reduces viscoelastic effects
  - Both thermosets and thermoplastics transition from glassy to rubbery behavior at glass transition temperature ($T_g$)
    - Thermoplastics also exhibit a melt temperature $T_m > T_g$
    - Composite service temperatures generally must be below $T_g$
- Metals and ceramics may also be used as matrix materials

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## Composites

- Fiber reinforcements provide tensile and compressive strength (in the fiber direction)
- Matrix material –
  - Binds and stabilizes the fibers
  - Provides load transfer around broken fibers
  - Carries loads perpendicular to fiber directions
  - Has primary influence on
    - Service temperature
    - Chemical resistance
    - Abrasion resistance

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## Sample Material Property Tables

- At end of chapters 1 and 2
  - Tables 1.3, 1.4: Properties of unidirectional composites
  - Tables 2.1, 2.2: Fiber properties
  - Tables 2.9, 2.10: Matrix properties

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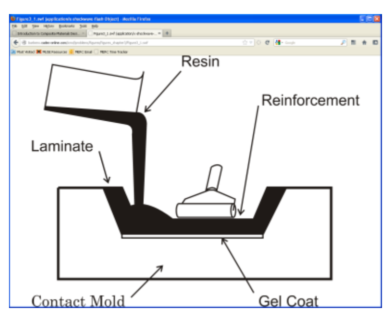
## Manufacturing Processes

- What is involved:
  - Impregnation of fibers with resin
  - Alignment of fiber directions
  - Consolidation to remove excess resin, air, and volatile products
  - Cure or solidification of polymer in the required shape
- All processes require a mold, either open or closed, of some sort

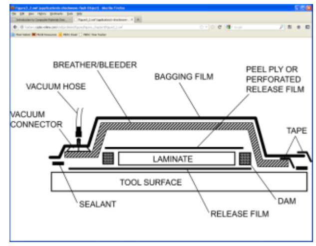
## Hand Layup

- Dry fiber is placed in the mold in desired orientations
- Liquid resin is poured over the fiber
- Rolling compacts and removes excess resin
- Room temperature or oven cured
- Low-cost tooling
- Labor-intensive



## Vacuum Bagging/Autoclave Processing

- Vacuum bagging may be used with hand layup to improve consolidation and remove volatiles during cure
- Autoclaves are basically pressurized ovens
  - Increase pressure and improve consolidation curing cure
  - Used in conjuction with vacuum bagging

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## Prepreg Layup

- The term “prepreg” is short for “pre-impregnated” reinforcement.
- Prepreg is purchased with the fibers, as either unidirectional tape or bi-directional fabric, already infused with the resin
- The resin is partially cured so the prepreg is tacky
- Must be refrigerated during storage
- May be vacuum bagged and autoclave cured
- More expensive raw materials than wet layup, but cleanup is less expensive

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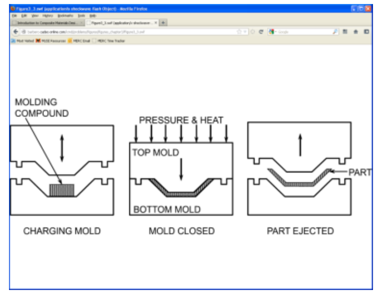
## Compression Molding

- Suitable for high volume production
- Most commonly used with chopped fiber prepreg or sheet molding compound (SMC)
- Precise fiber orientation is not possible
- Most suitable for secondary structure

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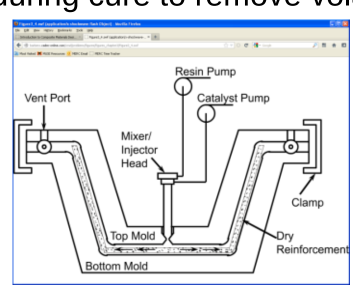
## Resin Transfer Molding (RTM)

- Dry fiber is laid into bottom mold at desired orientation.
- Mold is closed and resin is injected to fill the mold
- Curing is at elevated temperature
- Suitable for high volume, high performance parts
- In Vacuum-Assisted RTM (VARTM) a vacuum is pulled on the mold during cure to remove volatiles

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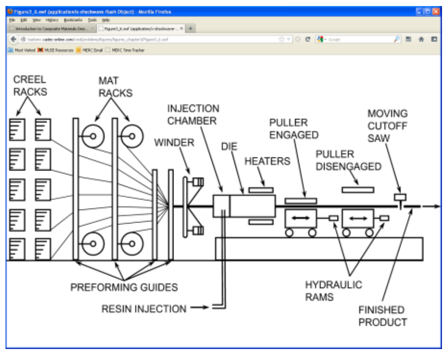
## Pultrusion

- Continuous process for producing constant cross-section parts (e.g. beams, tubes)
- Suitable for high volume, high performance parts

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## Filament Winding

- Ideal for the production of high-performance pressure vessels
- Wet-winding or prepreg (towpreg) winding
- More complex shapes can be produced: