Role of Fiber Reinforcement

- The mechanical properties of fiber reinforced PMCs dominated by the contribution of the fiber to the composite
- The four main factors that govern the fiber’s contribution are:
  - The basic mechanical properties of the fiber itself
  - The orientation of the fiber in the composite
  - The amount of fiber in the composite
  - The surface interaction of the fiber and resin

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Composite Preforms

- Chopped strand mat most ubiquitous preform
- Woven preforms can be tailored to achieve the best possible performance at the lowest possible cost.
- 2D woven preforms
- Braided preforms
- Preforms with multidirectional reinforcement.
Glass Fiber Reinforcements
(Material Forms)

- Roving (continuous strand)
- Chopped strand (0.125-2” long)
- Woven fabrics
- Continuous strand mat
- Chopped strand mat
- Milled fibers (0.032-0.125” long)
Roving

- Untwisted strand used for woven roving (heavier than yarn used in fabrics)
- Popular for fast buildup of laminate thickness where tight contours and drape are not an issue.
Glass Yarn

- Yarn ~ assemblage of fibers, generally <10,000 suitable for use in weaving into textile materials (lighter than roving.)
- Tow ~ large bundle of continuous fibers, generally 10,000 or more (not twisted)
Glass Yarn

- U.S. Yardage System: An exact system for identifying glass-fiber yarns is used because of the wide variety of types available (also TEX system.)
- Yarn nomenclature consists of 2 basic parts, one alphabetical and one numerical.

ECG-150 1/2

- First letter indicates the glass composition
- Second letter indicates whether the fibers are continuous or staple
- Third letter indicates the average diameter of the fibers from which the yarn is made

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## Glass Yarn

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*Code for fiber diameter, µin.*

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Glass Yarn

- The numbers used in glass-yarn nomenclature identify the basic strand weight and the yarn construction.
  - The strand weight is indicated by the first series of numbers, represents ~1/100th of the yards/lb
  - The second series designates the yarn construction
    - The first digit tells how many basic single strands/yarn
    - The second digit indicates the number of basic strands which are plied together.
    - To find the total number of strands in the yarn, multiply these 2 numbers together.
Glass Yarn

ECG 150 1/2

E = electrical glass
C = continuous filament
G = filament diameter ~ 350-399 μin.
150 = 15,000 yd/lb (nominal yardage)
1/2 = single strands twisted and two of the twisted strands plied together
Woven Fabrics

- Constructed of interlaced yarns, fibers, or filaments, usu. a planar structure (0.006-0.010”).
- Typically manufactured by interlacing warp (lengthwise) yarns and fill, or weft (crosswise) yarns on conventional weaving looms.
- The principal factors which define a given fabric style are fabric count, warp yarn, fill yarn, and weave.
Woven Fabrics

- Fabric count refers to the number of warp yarns (ends) per inch and the number of filling yarns (picks) per inch.
- Fabric count plus the properties of the warp and fill yarns used to weave fabrics are the principal factors which determine fabric strength.
Woven Fabrics

- The weave of a fabric refers to how warp yarns and fill yarns are interlaced.
- Weave determines the appearance and some of the handling and functional characteristics of a fabric.
- Popular weave patterns include plain, twill, crowfoot satin, long-shaft satin, leno, and unidirectional.
Plain weave is the oldest and most common textile weave.

One warp end is repetitively woven over one fill yarn and under the next.

It is the firmest, most stable construction, providing porosity and minimum slippage.

Strength is uniform in both directions.
Twill weaves have one or more warp ends passing over and under two, three or more picks in a regular pattern.

Such weaves drape better than a plain weave.
In the crowfoot, and long-shaft satin weaves one warp end is woven over several successive fill yarns, then under one fill yarn.

A configuration having one warp end passing over four and under one fill yarn is called a five-harness satin weave.

The satin weave is more pliable than the plain weave.

It conforms readily to compound curves and can be woven to a very high density.

Satin weaves are less open than other weaves.

Strength is high in both directions, less fiber crimp.

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Woven Fabrics

- The leno weave has two or more parallel warp ends interlocked.
- The unidirectional weave involves weaving a great number of larger yarns in one direction with fewer and generally smaller yarns in the other direction.
- Also available are nonwovens
  - Held together by an occasional small transverse strand or a periodic cross bond with resin.
Woven Roving

- Rovings can be woven into a product called woven roving.
- Heavier and thicker than fabrics
  - typically 12-40 oz./yd²
  - with thicknesses of 0.02-0.05”
- Usually provided in a plain weave.
- Usually molded by hand lay-up.
- Typical applications include: boats and cargo containers.

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Stitched Fabrics

- Fabric is binder free, held together only by stitching
- Offer mechanical performance increases of up to 20% in some properties over woven fabrics
  - Parallel non-crimp fibers bear the strain immediately upon being loaded
  - Stress points at warp/weft crossovers eliminated
  - Higher density of fibers can be achieved (more like layers of unidirectional)
Stitched Fabrics

Available in

- **Unidirectional**, 
- **0/90**, 
- **Multiaxial forms**
Mat Reinforcement

- Held together by resinous binders or mechanically bonded by needling.
- Used to fabricate isotropic laminates (15-50% \(W_f\)).
- The reinforcing ability of continuous strand mat and chopped strand mat are essentially the same but continuous mat can be molded to more complicated shapes without tearing.
- Reinforcing mats are distinguished by the binders used to hold them together, which may be high or low solubility.
  - High solubility binder used in hand layup or wherever rapid wetout and contour matching is important.
  - Low solubility binder used in press molding or wherever the flow of the liquid matrix resin may wash away or disrupt the strands.
Continuous roving can be chopped into short lengths, usu. 0.125-2” long.

Chopped strands are available with different sizings for compatibility with most plastics.

Chopped-strand materials are used in premix and wet-slurry molding as well as for reinforcement in thermoplastic molding compounds.
Milled Fibers

- Continuous strands can also be hammer-milled into short nodules of glass ranging in length from 0.015 to 0.25”.
- Many sizing materials are available on milled fibers for compatibility with polyesters, epoxies, etc.
- Milled fibers are generally used to provide anticrazing, body, and dimensional stability to potting compounds, adhesives, patching compounds, and putties.
Coupling Agents

- Mechanical properties of PMCs depend largely on the behavior of the bond between the fibers and matrix.
  - Glass is a polar material, it has a strong attraction to water.
  - Unprotected glass fibers attract a coating several molecular layers thick of water, which will have an adverse effect on the fiber/matrix bond.
  - Bond is improved by coating the fibers with a coupling agent or finish to promote greater adhesion (improves “wetting”), also reduces deterioration of the f/m interface with time.
Coupling Agents

- Coupling agents improve bond strength
- The ideal coupling agent should provide a low modulus flexible layer at the interface that will improve adhesive strength of the fiber/matrix bond and reduce the number of voids in the material.
  - **Chrome complexes** (bad for the environment)
  - Silane compounds
- Usefulness becomes much more pronounced if the composite is subject to moisture – the coupling agent will prevent the water from having a catastrophic effect on the interface adhesion.
Then what is Sizing?

- **Sizing** is a lubricant applied to the fragile glass yarns prior to weaving to eliminate tearing and destroying the structural integrity of the fabric.
- Common practice to burn off the sizing (700-800°F) → heat cleaned surface, then the **finish** is applied
- Fabric with the sizing still in place called **greige** goods or loom-state.
Carbon Fiber Reinforcements

Material Forms

- Continuous carbon fibers
- Unidirectional tape
- Woven fabrics
- Discontinuous carbon fibers
  - Milled fibers
  - Chopped fibers
  - Longer chopped fibers
Continuous Carbon Fibers

- Available in a variety of forms, including:
  - yarns or tows containing from 400 to 160,000 individual filaments.
  - Unidirectional preimpregnated tapes up to 48” wide
  - Fabrics of many weights and weaves
  - Individual carbon filaments, usu. 0.0003” or 8 µm in diameter
Woven Fabrics

- Significant cost savings often realized in molding with fabrics (due to reduced labor requirements), despite more expensive material costs.
- Some fabrics essentially unidirectional
- Satin-weave fabrics, particularly 8HS, retain most of the fiber characteristics in the composite and easily be draped over can complex mold shapes.
- Plain weave fabrics are less flexible and are suitable for flat or simple contoured parts, at a slight sacrifice in fiber-property translation.
Woven Fabrics

- PAN carbon usu. made by weaving carbonized yarn.
- Weaving costs increase with increasing fiber modulus.
- Pitch-derived fibers on the other hand can be woven at an intermediate processing stage, then converted into the high modulus product while in fabric form.
- The strength properties of pitch-based carbon fabrics do not yet approach those of PAN-based products
- Lower cost potential, and continually improving properties make pitch-derived product attractive
- Fabric usu. unfinished or greige (pronounced gray.)
- Carbon fibers cannot be heat cleaned or scoured, therefore cannot be given same lubrication as glass or Kevlar fibers, instead lubricated with 0.5-2% by weight epoxy resin sizing (optimized to improve adhesion.)
Braiding

- Braid consists of three or more continuous fiber tows intertwined to cross one another diagonally without twisting around each other.
- Braids can be made from all types of fiber, including hybrids.
- Repeatability and reduced assembly time with braided preforms compared to hand lay-up translate to lower cost in finished parts.
- New or improved fabrication processes – some combining braided and stitched reinforcements with RTM, filament winding and pultrusion – spell further cost reduction potential.
Braiding

- Tubular-shaped biaxial braided sleeves are the most recognizable form for use in composites (Chinese finger cuffs.)
  - These comprise flexible, free-standing, seamless fiber architecture with two sets of continuous tows running CW and CCW.
  - The common fiber angle or orientation in a biaxial braid is 45° (allows highest degree of conformability for parts with changing cross-sections.)
Braiding

- Triaxial braids use three sets of interwoven tows, incorporating axial fibers to provide unidirectional properties and lock in diameter.
- Significantly increases stiffness in a finished part.
- Much less conformable
Braiding

- Overbraiding directly onto a molding tool (mandrel) or core allows automated lay-up of multiple plies and greater arance of braid angle.
- A key advantage of braids is the efficient transfer of load among the fibers, which are continuous and mechanically locked together.
  - Braid can absorb a great deal of impact energy.
- Question of crimp?
  - 10-15% tensile property reduction
  - Boosts interlaminar shear significantly because of nesting
Braiding

- Cost cutting achieved through computer-controlled, automated braiding of net-shaped preforms
- A&P demonstrated new equipment that combines braiding and filament winding
- 3D braid in R&D stages
- Together with advanced RTM, shows great cost cutting potential.
- We will examine some manufacturing case studies later. . .
Prepreg

- Prepreg combines partially cured (B-stage) thermosetting resins with reinforcing fibers.
- Thermoplastics account for <3% of the current prepreg market.
- Nearly 100% of all advanced composite materials “qualified” for structural aerospace applications are prepreg systems that have been qualified down to the specific fiber, resin, and manufacturing method (at a cost of ~$20 million.)
Prepreg

- By using prepreg, the process of impregnating the fiber is separated from that of laying up the laminate or composite.
- Makes laying up much simpler and quicker, results in laminates of better quality
  - The proportion of resin to fiber is automatically kept constant and uniform
    - Helps ensure optimum strength in the cured laminate
    - Makes it possible to maintain strict control of weight distribution in large and small areas
  - Fiber orientation is also easily controlled
    - Maximizes strength and stiffness where they are needed
    - Minimizes weight of material needed to achieve desired properties

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Prepreg

- Disadvantages include:
  - High raw material costs
  - Solvent processing
  - Refrigerated storage
  - Documentation
Prepreg

- Prepreg is good and getting better
  - Most prepreg specs allow 2% void volume
  - Newly designed prepreg machinery with improved process control and solvent deflashing methods has yielded even lower void content.
  - Resin chemistry developments – lowered prepreg costs increased product quality
  - New formulations emerging – no longer require cold storage
  - Emergence of heavy tow reinforcements also lowering costs.
  - Carbon-fiber prepreg <$8/lb
Boron prepreg tapes generally include a supporting carrier of woven glass-reinforced plastic fabric.

Carbon prepreg

Cured ply thicknesses of 0.0056-0.0064” most common.
References

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- Owens Corning website, [www.owenscorning.com](http://www.owenscorning.com)
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- ASTM Specification D 579 (fabrics)