Introduction to Composite Materials

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http://www.egr.unlv.edu/~bj

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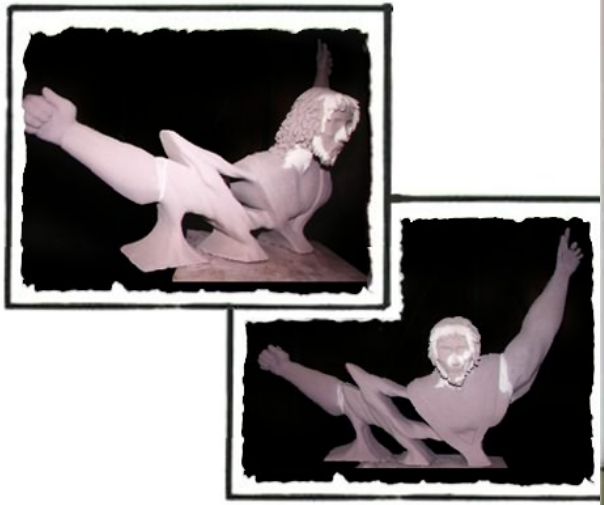
Materials In Entertainment Engineering…



Designer: Cindy Chinn
Artist: Cindy Chinn
Date: 1987

Materials Used in Entertainment Engineering

- **Depends on how you define entertainment engineering:**
  - Props for shows
  - Ornamental structures
  - Architectural simulations/re-creations
  - Hobby activities: model aircraft, race cars, model rockets
  - ???
- **For today, I will focus on:**
  - Sculpture materials for re-creations or original designs
  - Mold making materials
  - Polymers and composites for structural applications

Clay Sculptures for Slot Machine Handles

Foam Sculpting

Designer: Rhino Cast
Sculptor: Cindy Chinn
Date: 2002

This is a sample we did to demonstrate the process of foam sculpting. Many statues you see in Las Vegas are done using this process.

The original model was scanned in 3D, then enlarged and cut by CNC computer milling.

From there we completed the detail as shown in the top section.

Then a thin layer of drywall mud was applied to add firmness to the surface.

A hard coating of polymer is applied to protect the statue from the elements.

Finally, the statue is painted to match the desired look - in this case, weathered stone.

The entire process took 2 days to complete.

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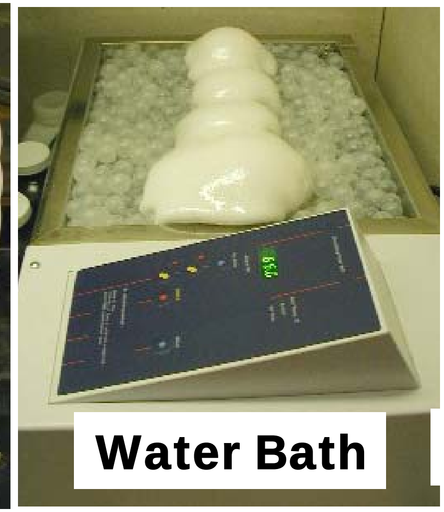
Processing of ReCrete Foam At UNLV

Mixing for 3.5 Min.

Ice Bath



Water Bath

Ambient

Foam Rises and Stays in Molds for 30 Min.

Post Cure at 66^{O}C for 4 Hours

Fabricated Foam

Foam Classifications

- Many materials can be foamed (polymers and metals)
- The most common types of foam used for molding:
  - Expanded Polystyrene
    - Usually white
    - Pilly …(Styrofoam coffee cups, cheap ice chests, etc.)
    - Can be cut with a hot wire
  - Extruded Polystyrene
    - Usually blue, panels used for home insulation
    - Can be cut with a hot wire
  - Rigid Polyurethane
    - Stronger and stiffer than polystyrene
    - Cannot be cut with a hot wire (toxic fumes)
    - Can be sanded easily to get a fine surface

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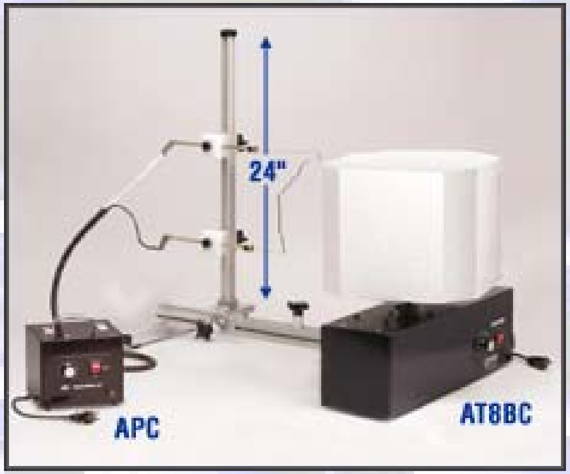
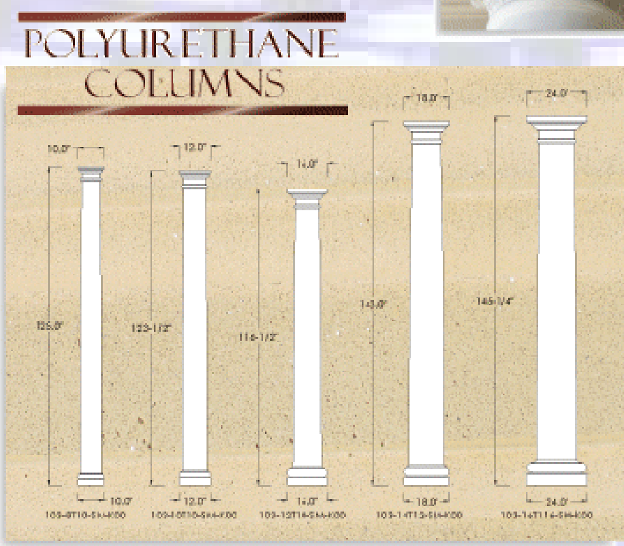
Foam Cutting

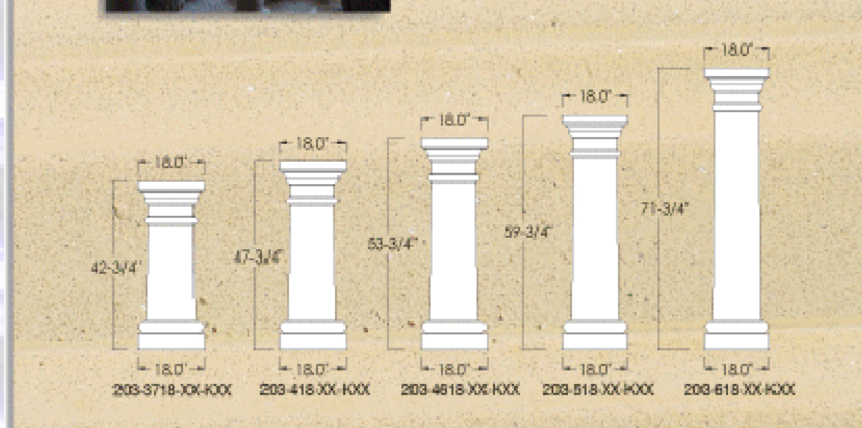


Architectural Foam Structures

Realm of Design, Henderson NV

COLUMNS





Products Made Possible With Composite Materials…

Composites

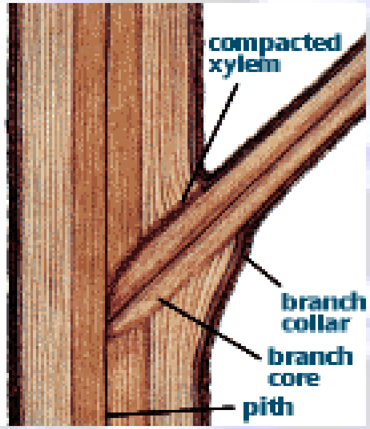
Composites are made from two or more distinct materials that when combined are better (stronger, tougher, and/or more durable) than each would be separately.

The word usually refers to the fiber-reinforced metal, polymer, and ceramic materials that were originally developed for aerospace use in the 1950s.

Although composites are a "high-technology" development, to some extent they mimic the features of living organisms such as the microstructures of wood and bioceramics like mollusk shells. The fibers and matrix of advanced composites may be combined using a variety of fabrication processes, with the choice depending on the desired alignment of fibers, the number of parts to be produced, the size and complexity of the parts, and so on. Perhaps best known for their use in **aerospace** applications, advanced composites are also used by the **automotive**, **biomedical**, and **sporting goods** markets. In addition, these strong, stiff, lightweight materials are seeing increased use in the rehabilitation, repair, and retrofit of **civil infrastructure**--including, for example, as replacement bridge decks and wrapping for concrete columns.

An Example of a Natural Composite

Composites do occur in nature--e.g., in tree trunks, spider webs, and mollusk shells. A tree is a good example of a natural composite, consisting of cellulose (the fibrous material) and lignin (a natural polymer) forming the woody cell walls and the cementing (reinforcing) material between them.



Complements of: http://www.ccm.udel.edu/

university homepage
college homepage
University of Delaware
Center for Composite Materials
sitemap
search

Manufacturing Fiberglass Composites

Hand-lay

Since the beginning of 1966 EM Fiberglas A/S has produced workpieces with the use of hand-lay and the experience of these many years has given EM Fiberglas A/S a large know-how in this area.

A continuously growing part of the hand-laid workpieces are now produced with advantage through vacuum moulding (RTM) due to the growing demands to the internal environment.

Advantages
Hand-lay has among others the following advantages:

- Possibility of producing very large workpieces
- Low moulding costs (advantage when producing small and medium series)

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Some Characteristics of Composites

Advantages

- High Mechanical Properties
- Flexibility of Design Options
- Ease of Fabrication
- Light Weight
- Corrosion Resistant
- Impact Resistant
- Excellent Fatigue Strength

Disadvantages

- Brittle Failure Mechanisms
- High Material Costs
- High Manufacturing Costs
- Temperature Limitations
- Actual Mechanical Properties not Always as Good as Expected
- Mechanical Properties Very Process Dependent

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Major Classifications of Composites

- Polymer Matrix
  - Material Systems
    - Thermoset & Thermoplastic Resin Systems
    - Glass, Carbon, Aramid Reinforcing Fibers
  - Product Classifications
    - Engineering Composites (lower cost, injection molded parts, fiberglass tooling and components)
    - Advanced Composites (high performance and higher cost materials)
- Carbon Carbon Composites
- Metal Matrix
- Ceramic Matrix
- Reinforced Concrete

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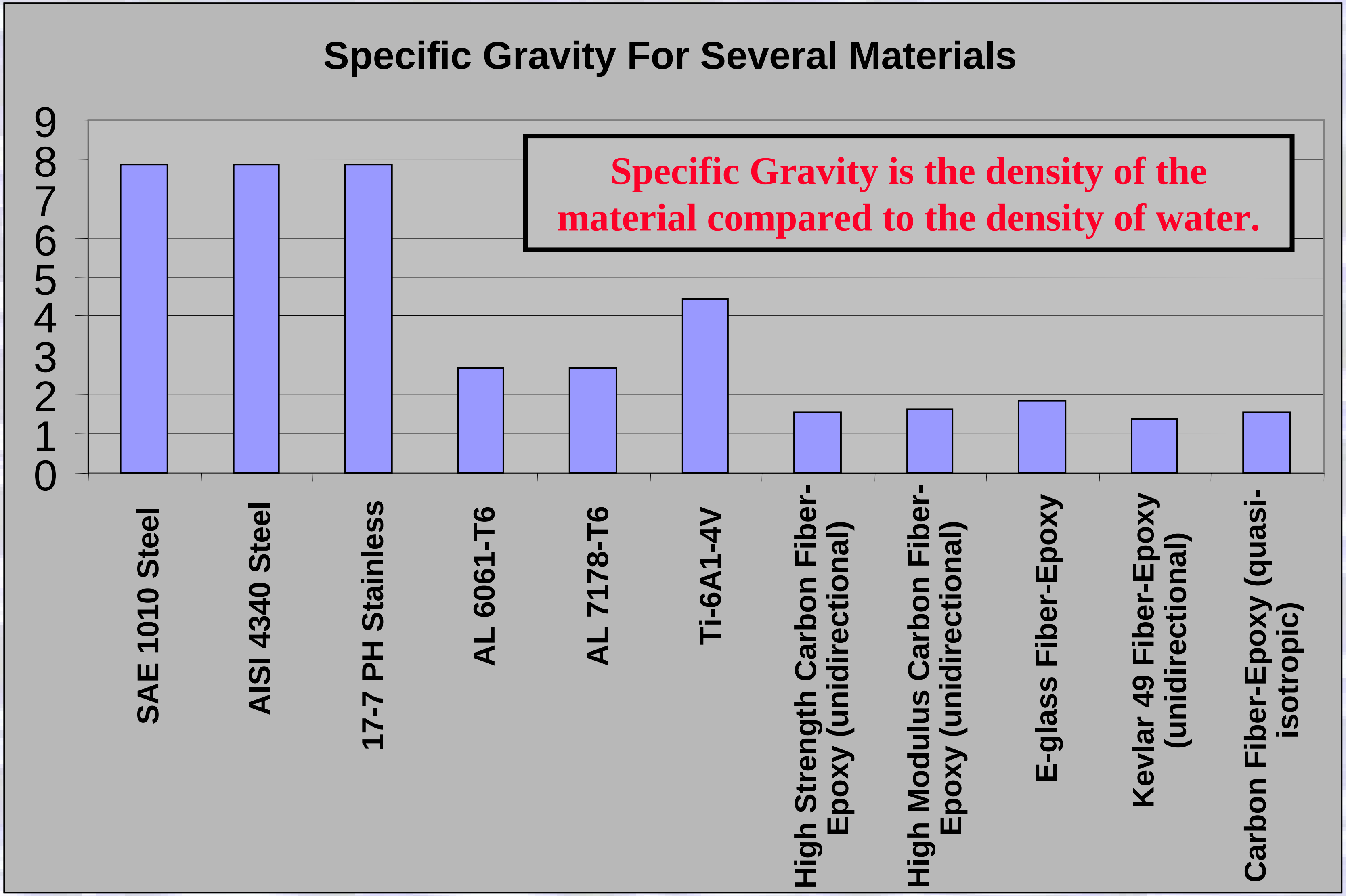
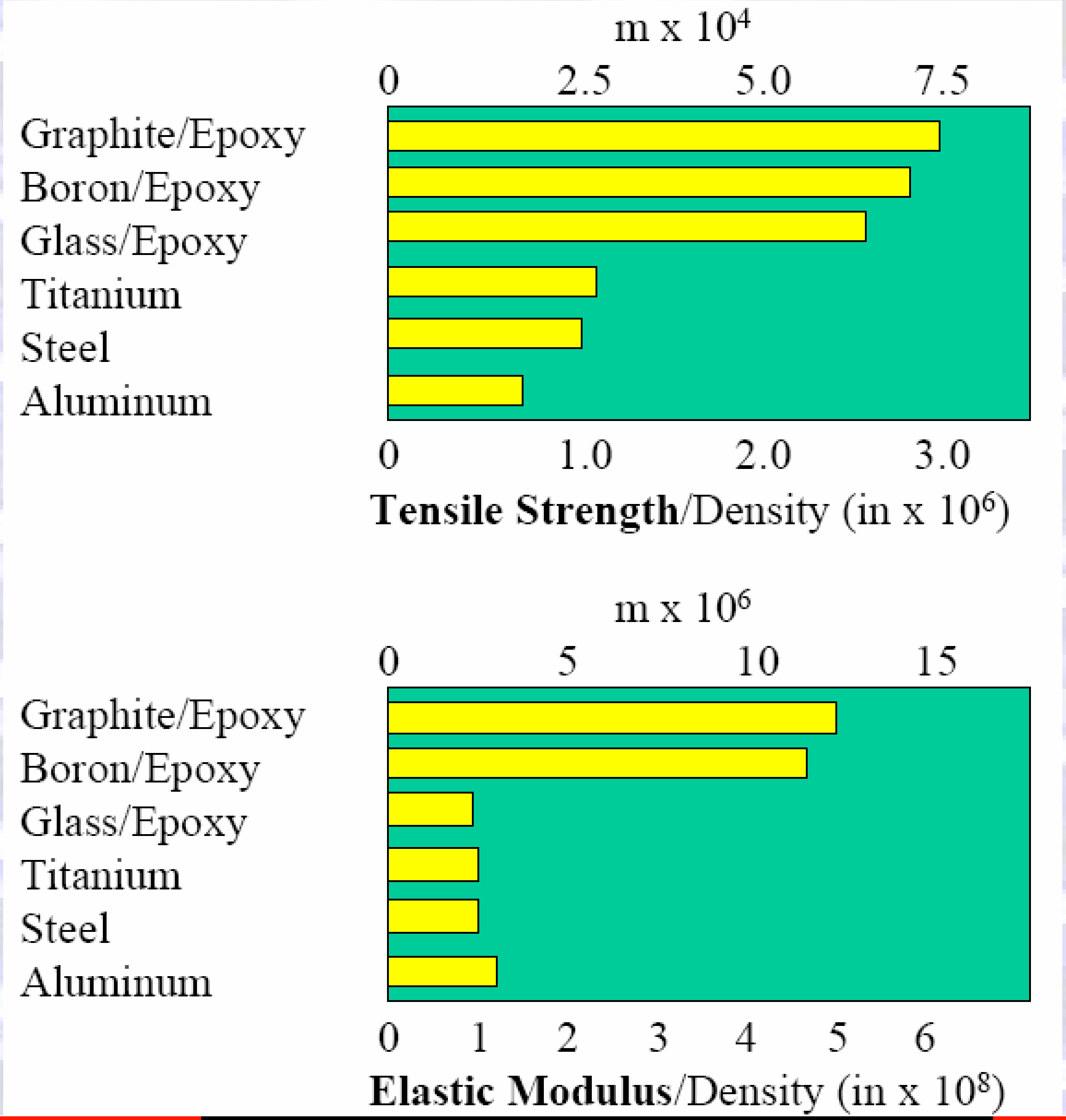
Specific Gravity For Several Materials



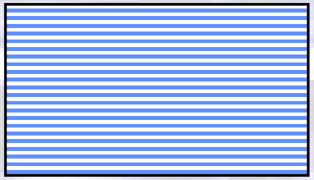
Specific Strength & Specific Modulus



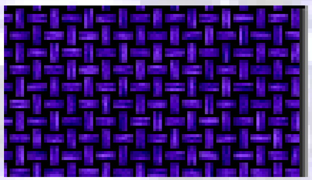
Materials Found in Composites

- Reinforcing Fibers (or particles)
- Matrix (holds fibers together)
- Others may include
  - Coatings
    - Improve bonding and load transfer at the fiber-matrix interface
  - Fillers
    - Added to polymers to reduce cost and improve dimensional stability

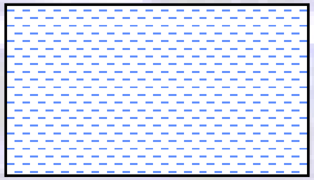
Basic Building Blocks of Fiber-Reinforced Composites



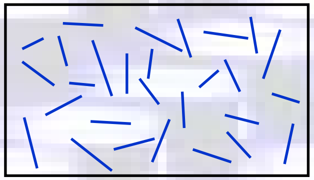
Unidirectional Continuous



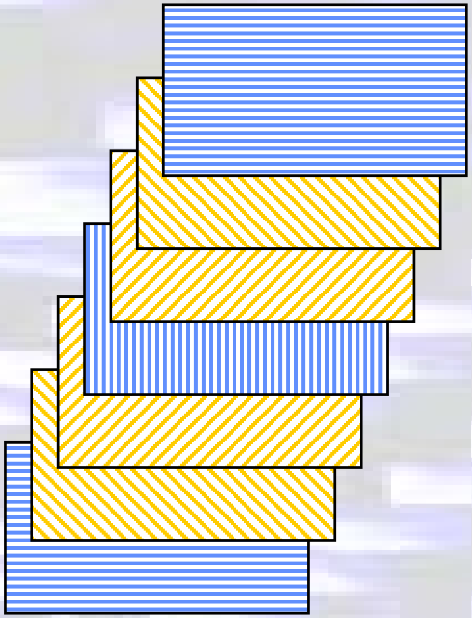
Bi-directional Continuous (e.g. woven fabrics)



Unidirectional Discontinuous



Random Discontinuous



Materials are formed into layers called lamina (ply, layer).

Lamina can be 0.004 - 0.04 inches thick.

Lamina with different fiber orientations (or different materials) are stacked to make laminates.

Fiber Reinforcements

- Fibers occupy the most volume in a high performance composite and carry most of the applied load.
- Fiber type, quantity and orientation have a major influence on the following properties of the composite:
  - Specific Gravity
  - Tensile Strength & Modulus
  - Compressive Strength & Modulus
  - Fatigue Strength
  - Electrical & Thermal Conductivity's
  - Cost

Fiber Properties Better Than Bulk Material Properties

- **Mechanical properties of fibers can be orders of magnitude greater than the same properties for the bulk material used to form the fibers.**
- **The bulk material may have flaws and defects which reduce stiffness and more noticeably, the strength.**
- **Process used to manufacture the fibers eliminates or reduces flaws resulting in better mechanical properties.**

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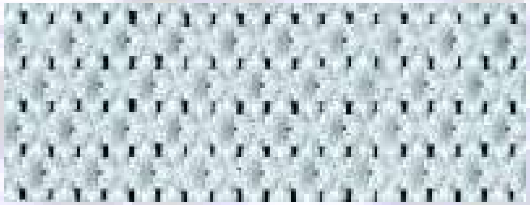
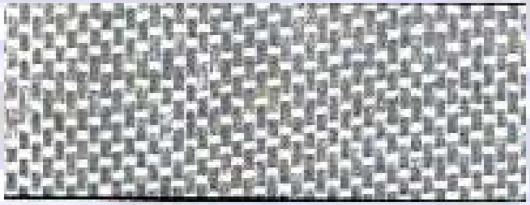
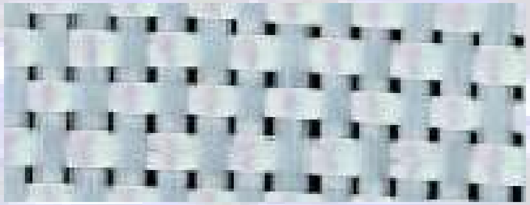
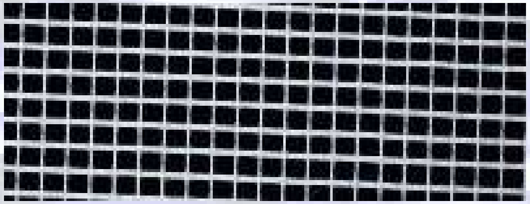
Fiberglass Reinforcement

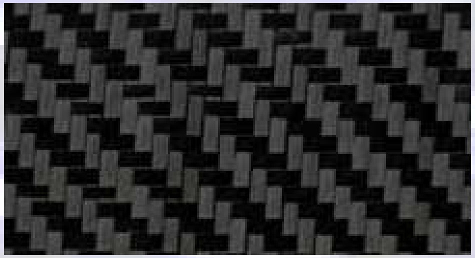
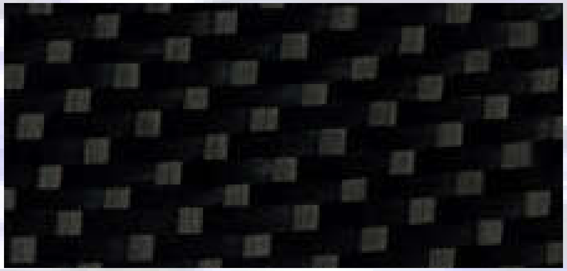






Glass Fibers

- **Raw Materials**:
  - silica sand, limestone, boric acid, etc.
- **Four major types used for composites**:
  - **E-glass**: good strength & electrical resistivity
  - **S-glass**: 40% higher strength, better retention of properties at elevated temperatures
  - **C-glass**: corrosion resistant
  - **Quartz**: low dielectric properties, good for antennae and radomes

Fiberglass Forms for Composites

- **Rovings:** used directly for some manufacturing processes (pultrusion, winding).
- **Fabrics:** made by weaving continuous rovings just like textiles
  - fabrics are usually compared by weight. Most glass fabrics weigh between 12 and 40 oz./sq. yd. The thickness varies from 0.02 to 0.04 inches.
- **Fiberglass Mats**
  - Chopped Strand Mat: randomly oriented 1-2 inch fibers
  - Continuous Strand Mat: unchopped spiraled fiber
  - Surface Veil: decorative fine weave which minimizes ‘telegraphing’ of primary structure

Carbon Fiber Reinforcement


Carbon Fibers (Graphite)

- **High Strength, High Modulus Fibers First Developed in the 1950's.**
- **Typical carbon fiber diameters are in the range from 5-10 μm.**
- **Continuous carbon fibers are grouped together in bundles called TOWS. There can be between 400 and 320,000 filaments per tow.**
- **Most tow sizes used in composites are in the 3k to 12k range.**
- **Carbon fiber tows can be processed in to composites directly or woven into fabrics**

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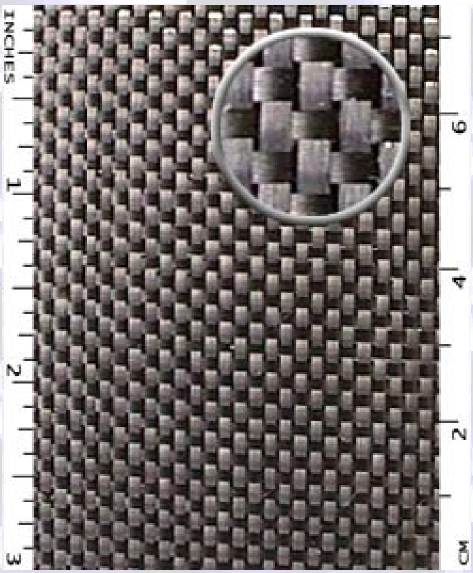
Comparison of 3K & 6K Carbon Fiber Fabrics

CARBCOM

100% CARBON FABRIC - 3K x 3K - PART # 3570-30AQ

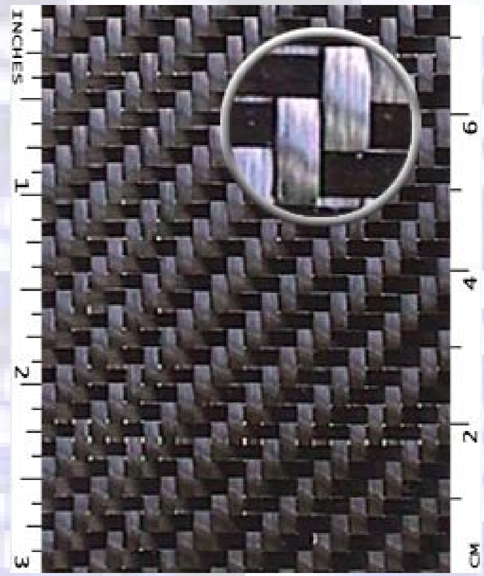


PART #: 3570-30AQ

Weight: 195g/5.7oz
Width: 76cm/30"
Weave Type: Plain
Warp Count: 12 ends/" (492/m)
Fill Count: 13 pics/" (492/m)
Warp Fiber: 3k Amoco T300
Fill Fiber: 3k Amoco T300

Thickness: 0.009"/0.0076 (dry/laminate)

100% CARBON FABRIC - 6K x 6K - PART# 61052-50TQ



PART #: 61052-50TQ

Weight: 362g/10.5oz
Width: 127cm/50"
Weave Type: 2x2-Twill
Warp Count: 11 ends/" (433/m)
Fill Count: 11 pics/" (433/m)
Warp Fiber: 6k TORAY T400
Fill Fiber: 6k TORAY T400

Thickness: 0.024"/0.017 (dry/laminate)

PART #	Price Format	List $US	1 + Roll	2 + Roll	5 + Roll	10 + Roll	25 + Roll
3570-30AQ	$Lin/yd	20.58	13.27	12.25	11.22	10.19	9.16
	$m2	29.54	19.05	17.57	16.10	14.62	13.14
FABRIC Carbon: 195g/5.7oz @ 76cm/30", Plain, 12.5x12.5pic, 3k x 3k, Amoco T300							

PART #	**Price Format**	**List $US**	**1 + Roll**	**2 + Roll**	**5 + Roll**	**10 + Roll**	**25 + Roll**
61052-50TQ	$Lin/yd	43.00	28.68	26.53	24.38	22.23	20.08
	$m2	37.03	24.70	22.85	20.99	19.14	17.29
FABRIC Carbon: 362g/10.5oz @ 127cm/50", 2x2-Twill, 11x11pic, 6k x 6k, TORAY T400							

http://www.carb.com/carbon.html

Organic Fiber Reinforcement (Kevlar, Spectra, …)

Organic Fibers

- **Aramid (Kevlar, Twaron)**
  - **First introduced commercially in 1971**
  - **Its' first commercial applications were in tires, industrial belts, bullet proof vest, high strength cloths, and composite structures**
  - **Several Types of Kevlar**
    - **Kevlar 29: high toughness**
    - **Kevlar 49: high modulus**
    - **Kevlar 149: ultra high modulus**
  - **In general Kevlar has high tensile strength and good damage tolerance but poor compressive strength.**
  - **Kevlar can have problems bonding to other resins**

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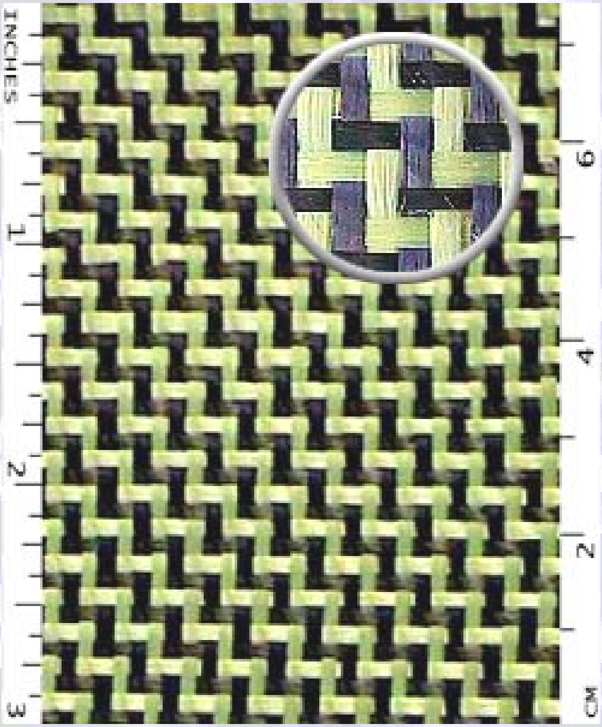
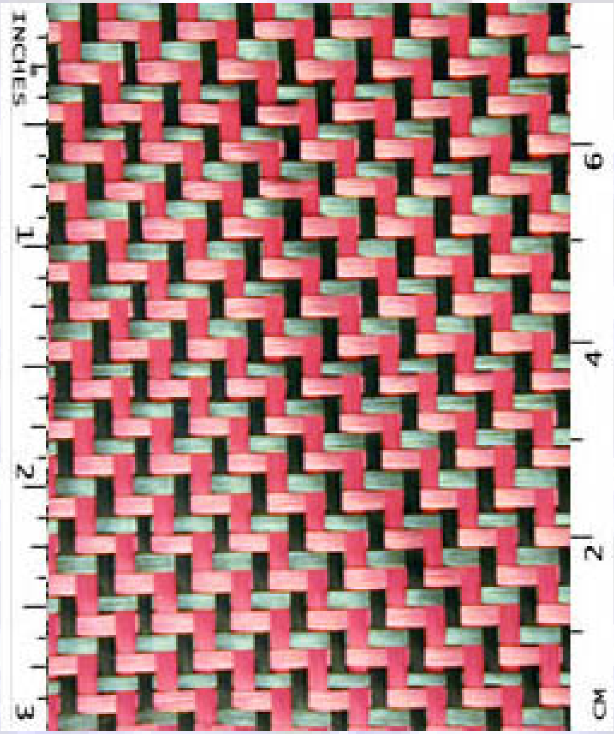
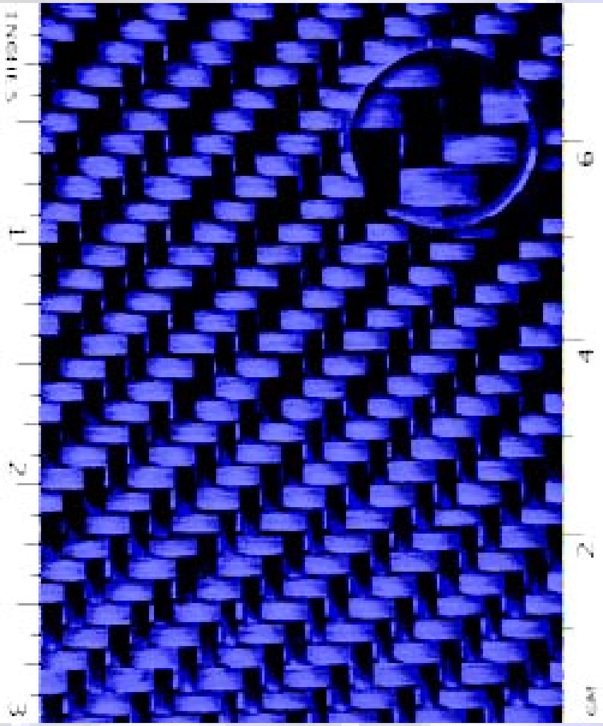
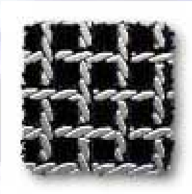
Carbon/Kevlar Hybrid Fabrics



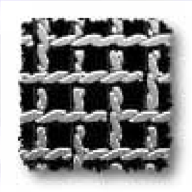




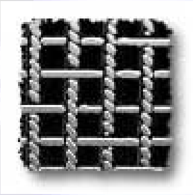
Standard Fabric Weave Patterns



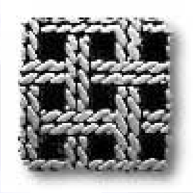
PLAIN WEAVE: The most simple and common of the weave patterns with warp and fill fibers crossing alternately. The most stable weave pattern.



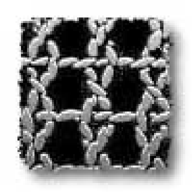
TWILL: A basic weave which enables a greater number of yarns per unit area than a plain weave, as each end floats over at least two or more consecutive picks. It looks different on each side and is characterized by a diagonal "twill" line.



SATIN WEAVE: The face of the fabric consists almost entirely of warp or fill "floats" produced when, for example, one fill fiber "floats" over three or more warp fibers and then drops under one. The two sides each have a different appearance. Typically used in the composites industry, it produces a drapable fabric which conforms easily to contoured surfaces.



BASKET WEAVE: A variation of the plain weave typically used in composites, in which two or more warp fibers cross two or more fill fibers; more pliable and stronger than a plain weave, but less stable because it is looser.



LENO: A locking type of weave. Two or more warp fibers cross over each other and interlace with fill fibers, which prevents shifting of fibers in "open weave" fabrics.

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Matrix Materials for Composites

- **Have two major roles**:
  - Transfer load to the reinforcement
  - Protect reinforcement from adverse conditions
- **Three major classes of matrix materials**
  - Polymers
    - Thermosets
    - Thermoplastics
  - Metals
  - Ceramics

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Thermoset Polymers

- In general, they are liquid resins at room temperature
- They undergo a curing process which cross-links their molecular structure
- Cannot be remelted or reprocessed
- More rigid than thermoplastics
- Can have long or short processing times
- Examples: epoxy, polyester, polyimides, phenolics

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Polyester Resins

- Have dominated the market for commercial fiberglass reinforced composites.
- Major applications include:
  - boat hulls, pools, tubs, ducting, car body panels, building panels, molded furniture, tubing, etc.
- Advantages: Low cost, low viscosity, fast cure time
- Disadvantages: Low temperature capability, poor weathering performance
- First patented in 1936, became widely used within 10 years

Polyester Resins

- Polyesters can contain substantial amounts of several ingredients:
  - Resin, catalyst, filler, accelerator
- A variety of polyesters exist for different applications depending on the desired properties:
  - flexibility, toughness (bowling balls, helmets), low shrinkage, weather resistance, chemical resistance, fire resistance

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Epoxy Resins

- Most common choice for advanced composite materials
- Advantages:
  - Better adhesion to fillers, fibers, and other substrates
  - Corrosion protection
  - Higher strength, Lower shrinkage
  - Good electrical an fatigue properties
- Disadvantages
  - Higher cost, long curing time
  - Poor appearance (yellowish)
- Applications
  - Potting & encapsulating for environmental protection, tooling, adhesive bonding, laminated & filament wound composites

Curing of Epoxies

- Epoxies start with an epoxy group
- Hardeners are added which react with the epoxy groups to form the cross linked polymer
- Curing time and temperature depend on the type and amount of hardener.
- Some epoxies react and cure at room temperature, others require heating to complete the reaction
- Cooling can slow down the reaction.

Manufacturing Methods for Composite Materials

- **Manual Lay-up or Spray-up**
- **Vacuum Bagging**
- **Autoclave Processing**
- **Filament Winding**
- **Pultrusion**
- **Matched Die Molding (SMC)**
- **Resin Transfer Molding**

All of these methods are tailored for the specific materials that are being processed. Polymer chemistry plays an important role in selecting the appropriate resin for a given fabrication method.

Composites Processing Summary

- **The processing usually involves a cycle (or multiple cycles) of applied temperature, pressure, and vacuum.**
- **Elevated temperature is used to:**
  - Initiate and sustain chemical reaction in thermoset resins
  - Melt thermoplastics
  - Reduce viscosity
- **Pressure is used to:**
  - Force the viscous resin-fiber material into a mold.
  - Compact a laminate
  - Squeeze out voids
- **Vacuum is used to help pull out trapped air or other gasses that may be produced during the chemical reaction.**

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Manual Lay-up Methods for Composites

- Begin with a mold
  - Apply mold release agent
- Apply a thin layer of catalyzed resin to form a gel coat
  - Protects from blistering, stains, weather, etc.
- Apply layer of fabric or mat reinforcing
- Pour, brush, or spray resin onto fiber reinforcement
- Use rollers to spread resin, flatten fibers, squeeze out trapped air
- Repeat for additional reinforcement layers
- Let cure.

Conventional hand layup for boat building

Vacuum Bag Molding Process

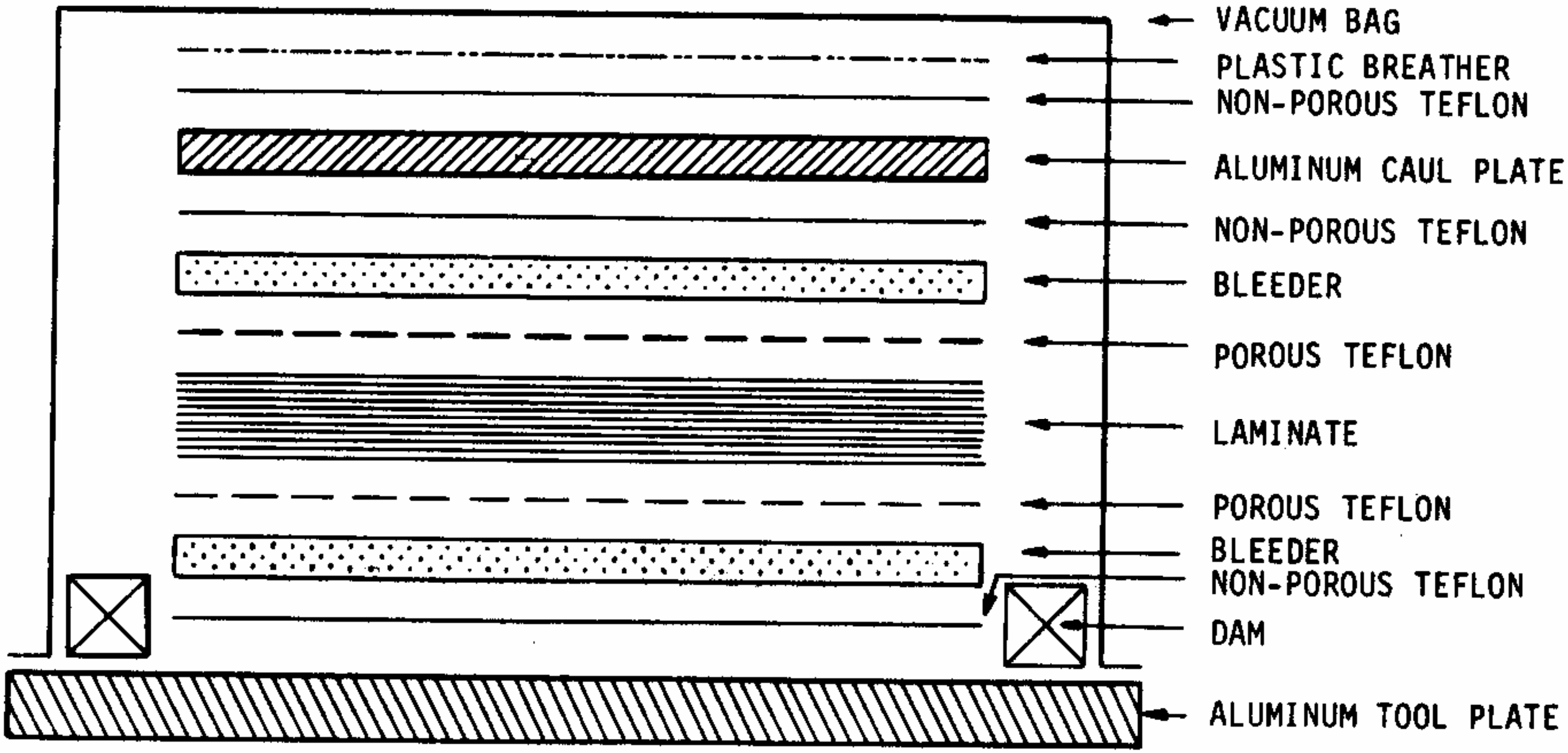


Figure 5.9 Schematic of a bag molding process.

Manual Lay-up of UNLV Human Powered Vehicle Fairing

Vacuum Bagging of UNLV Human Powered Vehicle Fairing

Finished Fairing

62 MPH !


26
UNLV
Silver State ASME
Bechtel Nevada Corp.
Composite Technologies

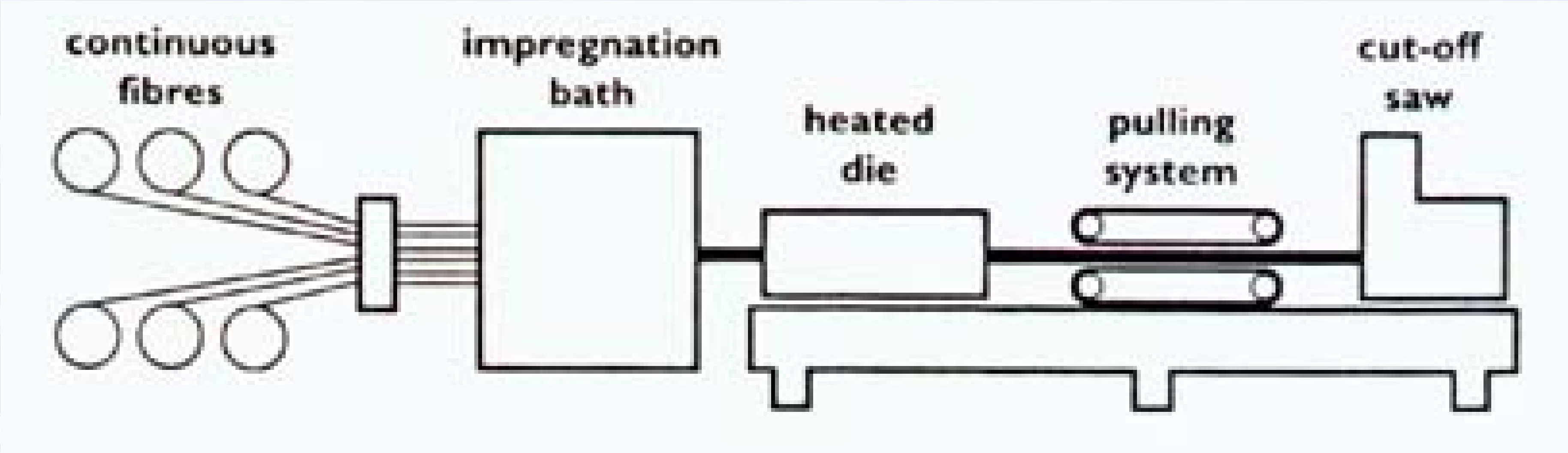
2005 Tandem HPV Fabrication

2005 Tandem HPV Competition

Autoclave Curing of Composites

- A prepreg composite part is generally prepared in the same manner as described for vacuum bagging.
- The entire assembly is then placed in an autoclave that is capable of applying both heat and pressure.

Pultrusion

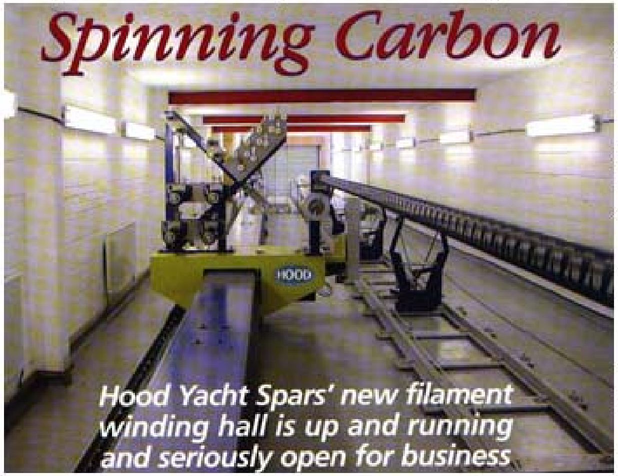

continuous fibres
impregnation bath
heated die
pulling system
cut-off saw

Filament Winding

HOOD Spinning Carbon yacht spars

Spinning Carbon | Filament Winding | Oyster 62 | Carbon Rigging

Computer controlled filament winding



4th April 2002 -- Hood Yacht Spars' new filament winding machine is up and running. Technical Chief Michael Orange recounts the design, commissioning and incredible performance of the new plant.

After assessing a number of US based suppliers of Filament Winding machines, we finally commissioned a local Essex based company Pultrex to build and install the equipment in our new 40 meter long filament winding hall. The whole project has taken 18 months to get to this stage.

The machine winds pre-preg carbon fibre, called 'tow-pregs', on to a mandrel from the delivery head which tracks backwards and forwards along the full length of the spar.

The rate of winding and the varying precise angles (right down to 7 degrees) at which fibre is applied are fully computer controlled to create spars with an ever changing aerofoil shape to a much greater accuracy than possible with conventional carbon lay-up processes.

The machine can lay down material at about 20kgs per hour and will typically wind a 30mtr spar in about 4 days. Currently we are using hi-tech T700 12k carbon fibre with epoxy pre-preg at 70% carbon to 30% resin by weight. All components are cured to 120°C which ensures that the mast will never get hot enough in the future to go either soft or brittle.

The 'strand by strand' filament winding process gives fantastic consolidation of the laminates. The process at 60-70 psi is the equivalent of 75% of autoclave pressure and exceeds standard vacuum bag pressure by 4-5 times.

Oyster 62 Mast

Composites References
(Trade Magazines & Websites)

Trade Magazines (Offer free subscriptions)

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The End

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