Materials
Materials Overview

The materials curriculum covers a variety of composites materials. Such as dry fabrics, advanced composites (pre-pregs), honeycomb, and unidirectional tape. Also included, is handling and storage as it is a very important in order for the materials to last its storage life. It is recommended to use a material log sheet when storing any materials.

Objectives

- Understand what composites are
- Understand the difference in resins
- Understand the different weave patterns
- Apply use of a material log sheets
- Define the advantages of using pre-preg materials
- Define the advantages of using core material
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What Are Composites

Advanced composites are characterized by the use of high-performance resin systems and high-strength, high-stiffness fiber reinforcement. There are a number of exotic resins and fibers used in advanced composites, however, epoxy resin and reinforcement fiber of aramid, carbon, or graphite dominates the market.

These materials have been adopted for use in many industries including aerospace, automotive, wind energy and sporting goods. The $70 billion-a-year industry is growing at a rate of 8% annually. The Advanced Composites Manufacturing Association estimates that more than 50,000 new products could utilize advanced composite materials.
History of Composites

1500BC
Egyptians use straw and mud to increase building strength.

1200AD
Mongols invent a composite bow made of wood, bone and animal remnants, allowing Genghis Khan to dominate opponents.

1865
John Mayo receives a patent for “wood sheets fastened together crosswise from each other to form a panel. This is considered an early plywood patent.

1900s
Scientists developed plastics that are superior to the resins that were previously used from animal sources.

1905
World’s fair in Portland, Oregon, a laminated wood veneer is introduced by the Portland Manufacturing Company and the composite “plywood” industry is born.

1915
The “grandfather of composites, Brandt Goldsworthy is born. He makes numerous contributions to the world of composites including the development of pultrusion.

1935
Owens Corning develops fiberglass.

1940s
Fiberglass is combined with plastic polymers creating Fiber Reinforced Polymers, commonly known as FRP.
In WWII, composites are used for Radomes, innovative technology allows the radomes to shield equipment from radio frequencies.
The use of composites in Aerospace begins with the F117 Stealth fighter.

1946
Composites go from military to the commercial industry when the first composite boat hull is introduced.
Fiberglass surfboards revolutionize the sport.

1953
First Chevy Corvette made of fiberglass comes off the production line.

1970s
Composites industry begins to grow. DuPont creates Kevlar - which is commonly known as bullet proof material used in vests, vehicles and other applications.
Carbon fiber introduced.

1989
The B2 Bomber built by Northrup Grumman for the US Air Force takes its first flight. Using “stealth” technology the B2 Bomber is made of composites and special coatings meant to deflect or absorb radar.

Today
Composites are used in almost every manufacturing industry including recreational – snow boards, skis, amusement park rides etc.
Robotics and SAE racing teams are using composites for their projects due to the lightweight and structural integrity.
The composite industry is currently focused on renewable wind energy and space technology. Many private companies are pressing the existing boundaries of aerospace, by developing aircrafts that meet the requirements for space.
Intro to Resins and Fabrics

Resin is a liquid plastic which can be crystal clear, or it can be colored with pigments. The types of resins generally used are Polyester resins and Epoxy resins. Both require two liquids to be mixed together in accurate proportions in order to start off the curing or hardening of the resin.

Polyester resins are used when the molds are deeper than 0.5”. Additionally, the casts can be poured all in one application rather than in layers. The most common type of polyester is a clear casting resin. Which is good for embedding objects or materials, (such as carbon fiber,) that you wish to display within your casting or lay-up.

Epoxy resins are mainly pouring/coating resins that are designed to be used in thin layers; to coat images, fill shallow bezels, or fill shallow molds. However there are also casting epoxy resins, which can be used in deeper molds. Epoxy resins are more expensive than polyester resins but they are not as toxic and give off less odor.

The “Catalyst” is a material that when mixed with resin creates a chemical reaction that starts the curing or hardening process in two part resin systems. Make sure you follow the resin instructions and add exactly the right amount of catalyst, as the wrong amount can cause problems later. Mix the components in disposable, un-waxed paper cups, using wood stirring sticks. Before the resin and catalyst are mixed, make sure you understand the “Pot-life” of the resin or the time during which the catalyzed resin remains liquid or “workable”. Once mixed you have a specific amount of time to work with the resin before it starts to gel.

A polymer matrix resin, sometimes referred to as plastic is either thermoplastic or thermostet resin. A thermoplastic is a polymer that becomes pliable or moldable above a specific temperature, and returns to a solid state upon cooling. A thermostet is polymer material that irreversibly cures. The cure may be done through heat (generally above 350°F), through a chemical reaction (two-part epoxy for example), or irradiation such as electron beam processing. Common thermostet resins include polyester, ISO polyester, vinyl ester, epoxy and phenolic. To reinforce the resins, we use fibers such as glass, carbon, aramid, graphite or other reinforcing materials. The combination of these materials results in a discernable reinforcing function in one or more directions along the aspect ratio (length to thickness). FRP (fiber reinforced polymer) composite may also contain fillers, additives and core materials.

There are a number of exotic resins and fibers used in advanced composites, however, epoxy resin and reinforcement fiber of aramid, carbon, or graphite dominates this segment of the market. These materials have been adopted by an enormous range of industries that touch our everyday lives. Advanced composites provide high strength-to-weight ratios which enables engineers to design high performance parts. ACMA (advanced composite materials
association) estimates that more than 50,000 new products could utilize advanced composite materials.

**Fabrics**

As stated earlier, reinforcement fibers used in composite fabrication such as fiberglass, carbon, aramid, and graphite, come in various forms such as Yarns, Roving, Chopped strands, Woven Fabric, and Mats. Reinforcement fibers can be woven into fabrics. Fibers running along the length of a roll are referred to as WARP fibers, and the fibers running across the width of a roll are WEFT fibers. There are several different fabric styles which are commonly used in the composite industry.

**Plain Weave**

Warp fibers are interlaced each time they cross Weft fibers, the resulting fabric is very stable but difficult to drape around sharp profile changes. Plain-weave fabrics can be woven with a heavy balance of fibers in the Warp direction giving a near unidirectional format.

**Twill Weave**

With a Twill weave, intercepts are offset by one fiber bundle creating a diagonal, “herring bone” pattern. Twill weave fabrics have a much more open weave, readily draping and conforming to complex profiles.

**Satin Weave**

In a Satin weave, a fiber bundle passes over a number of fiber bundles and then under one fiber bundle, producing a much flatter fabric that can be easily draped to a complex surface profile. However, due to the construction, satin weaves are unbalanced (fabric with one side consisting of mainly warp fibers while the other is mainly weft). The resultant imbalance must be accounted for in a laminate construction and it is normal practice to invert the plies around the neutral axis of the laminate.

These fabrics are manufactured in two forms, Dry fabrics, these are fabrics which require a two part resin system to be mixed and added to the fabrics that make up the composite matrix and will cure at room or low temperatures and Pre-preg fabrics which are fabrics that are pre-impregnated with a resin system and will only cure at temperatures above 250°F thus requiring a curing oven or autoclave.

When working with these materials proper material safety should always be practiced by wearing your PPE’s, understanding the MSDS that is supplied with these materials, and the proper handling and storage of these materials.
Introduction to Pre-pregs

Pre-preg is a term for “pre-impregnated” composite fibers where a resin matrix, such as epoxy, is already present. The fibers often take the form of a “weave” and the resin is used to bond them together and to other components during manufacture. The matrix is only partially cured to allow easy handling; this is called B-stage material and requires cold storage to prevent complete curing. B-stage pre-preg is always stored in cooled areas since heat accelerates complete polymerization. Therefore, composite structures that are built with pre-pregs will require an oven or autoclave to cure.

Pre-Impregnated Materials (Pre-pregs)

Composites are known by the industry term fiber-reinforced polymer or FRP. Pre-Preg materials or advanced composites are characterized by the use of expensive, high performance resin systems and high-strength, high-stiffness fiber reinforcement. Pre-impregnated materials consist of a fabric that is pre-impregnated with a resin matrix in a controlled manner. Most pre-preg materials will have the exact amount of resin impregnated in them. All pre-preg materials must be cured in a composite curing oven or an autoclave. Not all pre-preg materials will cure at the same temperature. Depending on the application or part the cure temperature will vary.

There are a number of manufacturers throughout the world producing pre-preg composite fabrics and films designed for the various industries. Some manufactures use distributors to stock, repackage, and distribute material. These distributors make purchasing small quantities of composite fabrics and films readily available. At times there are difficulties locating small quantities of materials due to availability, the set-up cost at the manufacture’s level, and backlog in production. It is recommended to forecast your material needs 30-60 days before starting a project.

When using composite materials make sure that the composite materials being purchased and being used are compatible with each other. Using 250° material with 350° material will not work together.

There is a vast market for composites, from low-cost to high-cost materials. Generally, the low-cost materials will perform differently than the high-cost material when curing it, working with it, and performance after curing.

The storage of advanced composite (pre-preg) material must be in accordance with the manufactures technical data sheet. The manufactures technical data sheet or MTDS may contain information about storage, handling, shelf life, tensile strength, and recommended time and temperature when curing.
The Advantages of Using Pre-preg Materials

There are a few advantages of using pre-preg materials over dry fabrics. Pre-preg materials weigh less than material that is impregnated or saturated during lay-up. The manufactures of pre-preg materials impregnate the fabric with the exact amount of resin for the fabric which means that the material will have maximum strength properties.

Pre-preg materials are much cleaner when laying up and also can be temporary vacuum bagged and finished later.

One advantage that pre-preg materials or composite materials have on any other product is that it can be engineered to perform a certain way. Unidirectional Tape (UDT, Unidirectional Graphite, or Uni-Tape) is the pre-preg material used to engineer the performance and is usually underneath the first and last ply of a composite part.

Pre-pregs are cure faster than materials used in a wet lay-up. Pre-pregs must be cured in an oven or autoclave with a cure profile for the part. All composite parts that are laid up will have a different cure profile according to the product used, the thickness of the part, and the type of tool being used. For example, a 250° pre-preg composite clipboard would have a cure profile that would cure the part in approximately 3.5 hours. That means the part must ramp up 3 to 5 degrees a minute from ambient temperature which would take approximately 67 minutes. Once it reaches 250° the temperature must be held there for 90 minutes. Once that 90 minutes has been reached the part must ramp 3 to 5 degrees a minutes until it reaches 135° which should take approximately 41 minutes. Once the part has reached 135° the vacuum source may be removed. This cure profile may change with each part that is laid up.
Pre-preg Basics

- Fill Face – The side of the fabric where the majority of the surface yarns running perpendicular to the Selvage. Fill face is always down when laminating unless your Work Order specifies differently.
- Warp Face – The material side where the majority of the surface yarns running parallel to the Selvage. Warp face is always to be laid face up, unless otherwise specified.
Warp Face/Surface – Majority of Warp Fibers Above Fill Fibers

Fill Face/Surface – Majority of Fill Fibers Above Warp Fibers
Introduction to Unidirectional Tape

Overview

Unidirectional tapes are made from filaments of carbon that are flat, not twisted like yarn, and provide the strengths and stiffness of carbon fiber in one direction only, thus enabling the maximum precision in orientation.

Objectives

- Exposing students to Pre-Preg Unidirectional tape
- Understanding the application of unitape
- How unitape can be engineered for specific applications

Unidirectional Tape

Unidirectional pre-preg tapes have been the standard within the aerospace industry for many years. The fiber is typically impregnated with thermosetting resins. The most common method of manufacture is to draw collimated raw (dry) strands into the impregnation machine where hot melted resins are combined with the strands using heat and pressure. Tape products have high strength in the fiber direction and virtually no strength across the fibers. The fibers are held in place by the resin. Tapes have a higher strength than woven fabrics.

The fibers in a unidirectional material run in one direction and the strength and stiffness is only in the direction of the fiber. Pre-impregnated (pre-preg) tape is an example of a unidirectional ply orientation.

A fiber is the primary load carrying element of the composite material. The composite material is only strong and stiff in the direction of the fibers. Unidirectional composites have predominant mechanical properties in one direction and are said to be an “isotropic”, having mechanical and/or physical properties that vary with direction relative to natural reference axes inherent in the material. Components made from fiber reinforced composites can be designed so that the fiber orientation produces optimum mechanical properties, but they can only approach the true isotropic nature of metals, such as aluminum and titanium.

The strength and stiffness of a composite buildup depends on the orientation sequence of the plies. The practical range of strength and stiffness of carbon fiber extends from values as low as those provided by fiberglass to as high as those provided by titanium. This range of values is determined by the orientation of the plies to the applied load. Proper selection of ply orientation in advanced composite materials is necessary to provide a structurally efficient design. The part might require 0° plies to react to axial loads, 345° plies to react to shear loads, and 90° plies to react to side loads. Because the strength design requirements are a function of the applied load direction, ply orientation and ply sequence have to be correct. It is critical during a repair to replace each damaged ply with a ply of the same material and ply orientation. Structural properties, such as stiffness, dimensional stability, and strength of a composite laminate, depend on the stacking sequence of the plies. The stacking sequence describes the distribution of ply orientations through the laminate thickness. As the number of plies with chosen orientations increases, more
stacking sequences are possible. For example, a symmetric eight-ply laminate with four different ply orientations has 24 different stacking sequences.

Unidirectional Tape Ply Stack: Balanced
Material Handling and Storage

The storage of your advanced composite materials needs to be in accordance with the MTDS (Manufacture Technical Data Sheet) in addition to any specification that may apply. Most manufacturers state a storage life of the material on the data sheet. For example, a manufacturer’s data sheet may indicate to store material at 0°F for 450 days from date of shipment. It is important that we understand that this does not mean that the material will turn to stone on the 451st day. The information on the data sheet is simply the material supplier’s statement that defines the manufacturers recommended shelf life. Remember, manufacturers are in the business of selling more material.

Composite pre-pregs are an excellent example of a shelf-life controlled item. Pay close attention to your available inventory and maintain a log sheet on all perishable goods. That being said, not all composites are the same. Composites are like fresh produce or a gallon of milk. Many composites have different expiration dates. Take note that different industries maintain varied standards for maintaining shelf-life and storage conditions of composites. Be knowledgeable of the material standards related to your specific industry.

Handling begins when the material is initially received. Once the material information has been logged in the material log book, pre-kit the material into the size and quantities that best meet product applications. Ensure that all material is packaged and labeled properly. Identify the material part number, quantity, description, and expiration date on the outside of the material package. Verify that all material is sealed in a 6-mil poly-tube bag with a desiccant. Adding the desiccant helps to absorb any moisture that may be present within the sealed bag. The next step is to place the bagged and sealed product in the freezer.

Place all rolls weighing over 20 pounds on support racks within the freezer. Support racks prevent the rolls from forming a flat side during the freezing process. A deformity in a roll may cause processing issues when the material is used on future projects. Flat-kitted material may be stored in the freezer on a flat, even surface. Once material is thoroughly frozen you may choose to stack or store material vertically to minimize storage space. At this point categorize your freezer by storing the low-temp material at one end and the high-temp at the other end. Performing this organizational task from the beginning will help to streamline your processes and add to operational efficiencies. You will experience the benefit when you are pulling material for a future project and are able to easily locate the required material.
Each storage freezer should have a material Log Book/Freezer Log. The material log book should consist of the following information:

(1) **Material Log Sheet** – The log sheet needs to include: the part number, description, quantity, and expiration date. The log sheet keeps track of the accumulated time the material is in and out of the freezer, as well as the quantity of inventory remaining in stock.

(2) **Manufacturer Technical Data Sheet** – data that you may find useful in particular applications.

(3) **Notes** – The MTDS is a quick reference to the manufacturer’s recommendations on time and temperature involved in the cure cycle. The technical data sheet also includes other notes of process or procedural successes or failures, as they relate to your work projects.

(4) **Safety Data Sheet (SDS)** – Keep a copy of the SDS in the material log book for quick reference.

All composite shops must maintain and manage the shelf life of a sufficient level of quality inventory. When planning future composite projects you must be able to accurately monitor the following factors of your inventory:

**QUALITY, QUANTITY, and SHELF LIFE.**

Evaluating your inventory through the use of a log book will bring efficiencies to your processes and procedures. Making a guess at the quality and quantity of material will eventually cause costly downtime. Downtime could potentially cost hundreds of dollars or worse, cost you the loss of valuable customers or clients.
Material Label Definitions
*Including but not limited to

**STOCK CODE** - Unique number assigned to identify a material in the system database. PP=Prepreg, AD = Adhesive, FI = Film Adhesive

**CONTROL NUMBER** - Number assigned to an incoming material that provides traceability to material certification / vendor records. This control number for material covers an entire batch received at one time.

**ROLL NUMBER** - Is a number that is assigned at the time of receipt that distinguishes one roll form another in a like batch of material.

**MATERIAL TYPE** - Is the customer identifier that is used to distinguish one material specification from another. CL = Class, STY is the style or type of fiber used.

**RETEST** - Is the allowable time frame from the time the material is produced that we are allowed before retesting according to the specification must occur.

**DNUA** - Do No Use After - This is the date where we can no longer use the material due to specification retest allowances.

**EXPOSURE HOURS ALLOWED** - The maximum amount of hours allowed outside of the freezer at room temperature.

**EXPOSURE HOURS** - The current number of hours that are on the roll of material at the point the material was put in the freezer and time stopped.

**CPT** - Is the calculated date if the material were to sit outside of the freezer before it would expire. This is normally written on a small post it note so it can be easily changed if the material goes in the freezer.

**INSPECTOR** - The receiving inspector who verified the material and the test data.

**YARDAGE** - The amount on the roll when received and recorded after each use.

**STOP** - The date and time stamp when the material was put into the freezer. Could be multiple end times.

**START** - The date and time stamp when the material was taken out of the freezer. Could be multiple start times.
Material Log Sheet

<table>
<thead>
<tr>
<th>Material</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Qty Received</td>
<td></td>
</tr>
<tr>
<td>Roll Number</td>
<td>Batch Number</td>
</tr>
<tr>
<td>Freezer In Date/Time</td>
<td>Freezer Out Date/Time</td>
</tr>
<tr>
<td>Out Time Prior to Receiving</td>
<td>Total Out Time</td>
</tr>
</tbody>
</table>

Exposure Hours

<table>
<thead>
<tr>
<th>Date</th>
<th>Time Out</th>
<th>Date</th>
<th>Time In</th>
<th>Total Out Time</th>
<th>Initial</th>
</tr>
</thead>
</table>
Introduction to Honeycomb

Honeycomb core material is widely used in composite fabrication for sandwich panel construction. It is utilized in the aircraft, automotive, marine, and aerospace industry mainly for its light weight, high strength, and high stiffness properties. This equates to durability and lower fuel consumption which is a primary concern to manufacturers of these kinds of composite products.

Safety Considerations

Core preparation, processing, potting compound mixing, application, and splicing brings you into contact with chemicals in which you need to be protected from. Protective gloves must be worn to protect your hands from these chemicals. A particle mask should be worn to protect you from hazardous airborne particles. Ear protection must be worn due to the loud noises caused by mechanical sanders, air tools, and other loud equipment.

Fundamentals of Core Construction

Core composite construction (commonly called “sandwich” construction) is frequently found in all types of advanced composite designs, from spacecraft structures to small boats to aircraft floorboards. The primary reason is the very high stiffness-to-weight ratios which are available in a relatively inexpensive, easy-to-build structure.

The main function of any core material is to hold the skins apart. The low-density core material supports the thin skins, and keeps them from buckling when subjected to bending loads. Loads are transmitted from one skin to the other through the core, thus, the core is subjected to significant loads, especially shear.

In floorboards and other similar structures, the core material also has to be able to resist crushing from point loading caused by things such as wheels, high heels, etc. often “spike heel” loading becomes the design driver for an entire structure.
Advantages of Sandwich Panels

The main benefit of sandwich construction is a high stiffness-to-weight ratio.

<table>
<thead>
<tr>
<th>Relative Stiffness</th>
<th>100%</th>
<th>700%</th>
<th>3700%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative Strength</td>
<td>100%</td>
<td>350%</td>
<td>925%</td>
</tr>
<tr>
<td>Relative Weight</td>
<td>100%</td>
<td>103%</td>
<td>106%</td>
</tr>
</tbody>
</table>

The above diagram begins with a solid laminate of thickness “t”, showing the stiffness, strength, and weight of that laminate. It then shows two other panels where the laminate is split into two with different thicknesses with core in the middle. There is a considerable improvement in stiffness and strength as the core thickness increases, while the weight has a small increase.
Common Core Materials
- Honeycomb
- High Density Foam

Common Types
The most common types of honeycomb core materials used in aerospace construction are made from Nomex (aramid paper), fiberglass, or aluminum. Many specialty types of honeycomb are available, such as titanium, graphite, and various others.

Common Cell Shapes
The most common honeycomb cell shape is the hexagon, known as Hex Core. This cell shape is suitable for making flat panels, and can be heat formed into curved shapes. However, it is difficult to curve the core without creating opposite curvature 90° to the direction of the original curvature. (This is known as “anticlastic” curvature).

Hexagonal Core
Most common cellular configuration

Ribbon Direction
Hex core which has been “over-expanded” during manufacturing is called O-X core. The shape of this cell is still six-sided, but it is a “flattened” hexagon. This creates a honeycomb which is easily curved through tight radii in the ribbon direction, and is commonly used in making structures with simple (2-D) curves. It is slightly more expensive than hex Core.

Flex core is capable of 3-D (compound) curvatures, such as those found in nose cones and radomes. The cell shape is unrelated to Hex and O-X cores, and looks a bit like a Sombrero. It is a good deal more expensive than Hex and O-X cores.
Foam Core

Foam cores have a different set of properties in comparison to honeycomb. Foam in aircrafts are usually used for interior panels. It is often used along edges of honeycomb sandwich panels to seal against water or provide a good surface for finishing.
Core Processing
- Handling & Storage

When handling core, gloves should be worn at all times due to sharp edges. It should be stored in such a manner that it is not exposed to water, oil, or any other contaminants that will be detrimental to bonding. Additionally, stored core should be stacked to minimize damage.

Foam absorbs moisture from the air. Foam should be kept as dry as possible during storage and preferably kept in a humidity-controlled room.

When processing honeycomb core, some parts require a certain orientation of the core for strength purposes. The ribbon direction runs parallel to nodes in the honeycomb core. Transverse direction is perpendicular. The core orientation is illustrated in the figure below.

![Diagram of honeycomb core with labels: T - Thickness of cell depth, L - Ribbon (or longitudinal) direction, W - Transverse direction, d - Cell Size, n - Node]
Core Cutting

Before cutting any honeycomb core, inspect it for any core crush, depression, or separation. Core crush is the collapse, distortion, or compression of core. Core depression is a localized indentation or gouge in the core. Core separation is a partial or complete breakage of the core node bond. Avoid using any section of core that contains any of these discrepancies.

When cutting core, use a sharp utility knife and a core cutting template. A core cutting template can be premade before manufacturing a part. Be sure to keep the utility knife straight and butted against the template. Cutting a full edge with one stroke makes for a better final cut than making short cuts along the edge. Core cutting templates are usually made of fiberglass, polycarbonate, or aluminum.

Honeycomb core is commonly chamfered to remove any sharp edges and burrs. Chamfers also prevent crushing of parts in cure. A chamfer is a beveled or slanted edge of core. There are certain specifications or drawings that will give the required degree of the chamfer. Common core chamfer guidelines are shown. In order to create the chamfer there is an angled blade saw that could be adjusted to the proper angle. Once the core is chamfered with the saw it will need to be sanded. Sanding removes any sharp edges and creates a smooth surface for adhesive and skin plies to adhere to. Be careful not to over sand.
FIGURE 16 TYPICAL HONEYCOMB CORE CHAMFER

**CAUTION**

Knife edge (Detail B) is fragile requiring extra care in handling.
Chamfer intersections may be rounded off, tapering from Point D (0.5 to 2.0 inch R) to Point C (0 to 0.15 inch R).

Core chamfer intersection prior to forming radius

Cut out in core

Point C

Point D

Core chamfer

Honeycomb core

Cut out in core

Honeycomb core

View A–A