AME 486 – Aerospace Structures II

Project 1+2

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PRJ 1 #1

1. Yes, both of us read and understand the syllabus

PRJ 1 #2

- A composite material system, is a combination of two or more materials that when put together enhance the materials capabilities (strength)
  - Matrix + Fiber
  - The matrix binds the fibers (filler/reinforcement) and creates a system that is lighter, stronger, and more durable
- Matrix
  - Material component that holds the fiber and binds fibers together
  - Has a low density, ductile characteristics, and provides shape for the structure
- Fiber
  - Known as the “filler” material
  - Carries between 75-95% of the load – this is the load carrying element in the structure
  - Provides thermal stability as well as strength/stiffness
  - Fiber can be used for electrical conductivity or insulation in some cases

PRJ 1 #3

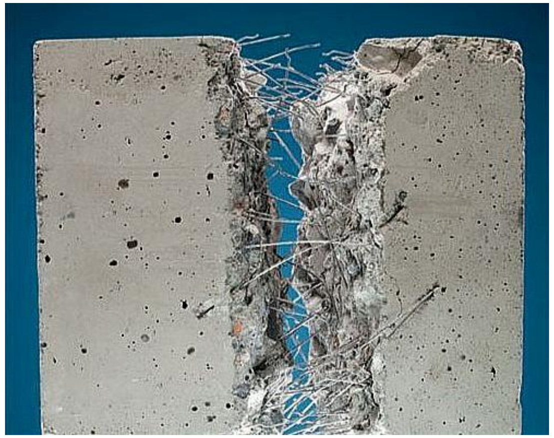
- No, composites are not always the best choice and depend on the following
  - Life of the program
  - Schedule
  - Costs
  - Overhead
  - Complexity
- More downsides include the following
  - Manufacturing variability – lots of variability, properties are direction dependent and require close attention to detail (fiber orientation, curing procedure, transportation, all variables that needs to be accounted for)
  - Compatibility with other materials - joining composites with metallic structures can be hard and introduce new problems
    - Bonding with other structures needs to be optimized, some materials don’t work with others (CTE)
  - Repairing – labor intensive, complex, and expensive
  - Recycling/disposing – a prominent challenge today, most composites cannot be recycled leading to environmental and waste issues

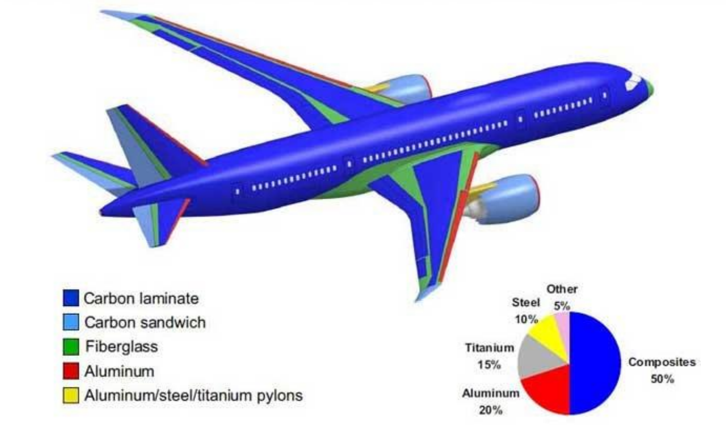
PRJ 1 #4

Composites are used in automobiles, particularly for race car wings, as they offer a high strength-to-weight ratio, reducing weight while maintaining aerodynamic efficiency, resistance to flexing, and durability.

Composites are used in the medical field. Prosthetic limbs made out of composites are lightweight, comfortable, and durable.

Building materials such as fiber reinforced concrete are stronger, more durable, and more crack resistant than traditional concrete. Fibers distribute load more evenly, reducing stress concentrations within the material.





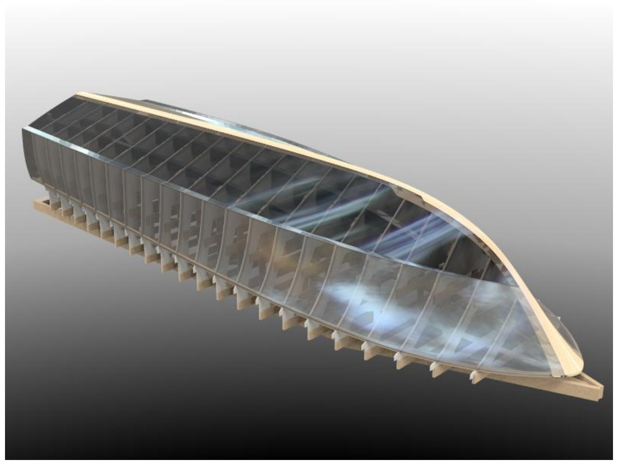
In aerospace, a Boeing 787 is made up of 50% composites to reduce weight, improve fuel efficiency, and enhance performance. Composites also have better corrosion and fatigue resistance.

PRJ 1 #4 CONT.

Composites for sports to enhance performance, durability, and weight. Seen in tennis, golf, hockey, speed bicycles.

Brackets/joints/fittings - High performance thermoplastic composite components made for aerospace applications. Exact model is Xycomp DLF – 35-50% weight reduction, better impact, fatigue, and thermal performance with excellent chemical resistance and is recyclable.

Kevlar composite body armor for ballistic resistance. Lightweight and relatively thin – good for on person protection.



Composites for boat hulls – lightweight (good for floating), corrosion resistant, and have good impact resistance.

PRJ 1 #4 CONT.

Composites for COPVs (Composite Overwrapped Pressure Vessels) are used in aerospace to store pressurized gas/liquid with reduced mass and are now also utilized in industries such as public transportation (buses) and firefighter gear.

Turbine blades or wind turbine blades are lightweight, durable, heat-resistant, and more resistant to corrosion. This improves performance and efficiency for the engine. Composites also have good fatigue resistance which lower service costs and have a greater stiffness to weight ratio.

PRJ 1 #5

- Supplies needed
  - 6oz woven carbon
  - 12oz carbon biaxial
  - 5/8 Corecell M100 Foam
  - Proset Lam 135/224 resin epoxy
- Steps
  - Cut the prepreg –place tape along the cutting lines to prevent fraying, then lay it on a table covered with painter's plastic
  - Apply resin – spread the resin evenly over the prepreg and allow it to soak through
    - Minimize resin usage – use as little resin as possible, avoiding puddles - work by feel
  - Remove air bubbles – fold the painter's plastic over the carbon, then press out air bubbles and excess resin with a metal roller
  - Apply resin to 12 oz Biaxial – coat the biaxial fabric with resin and ensure it is fully soaked through
    - Maintain fiber to resin ratio – aim for a 50% fiber to weight ratio for optimal strength
  - Peel and roll the woven carbon – remove the backing, roll it out, apply to the table, and peel off the top plastic layer
  - Layering process – apply the biaxial fabric on top of the first 6oz woven carbon
  - Resin application on the core – use a minimal amount of resin to prevent the core from absorbing too much from the carbon
  - Final layering – place the last 12oz ply and lastly, the 6oz ply on top of the foam core
  - Roll It Out – ensure even distribution of resin and adhesion of layers
    - Be carful not to over roll or squeeze all the resin out
  - Vacuum bagging – place P-3 perforated film on top of structure, followed by a breather fabric, then seal it with a vacuum bag
  - Vacuum process – activate the vacuum to compress the layers and remove any trapped air for a strong and uniform composite

PRJ 1 #5 CONT.

- Lesson learned
    - Do not use too much resin, aim for a 50% ratio
    - Make sure resin is evenly distributed and roll after every step of the way to ensure no air is trapped
        - Do not roll out all resin, only a minimal amount is needed
    - For thick 12oz material use a thicker adhesion plastic
    - Keep a clean work surface, the carbon can fray use tape for the edges
    - The vacuum bag in the video was too small but it worked, always size up for a vacuum bag
        - Make sure the seal on the vacuum bag is excellent

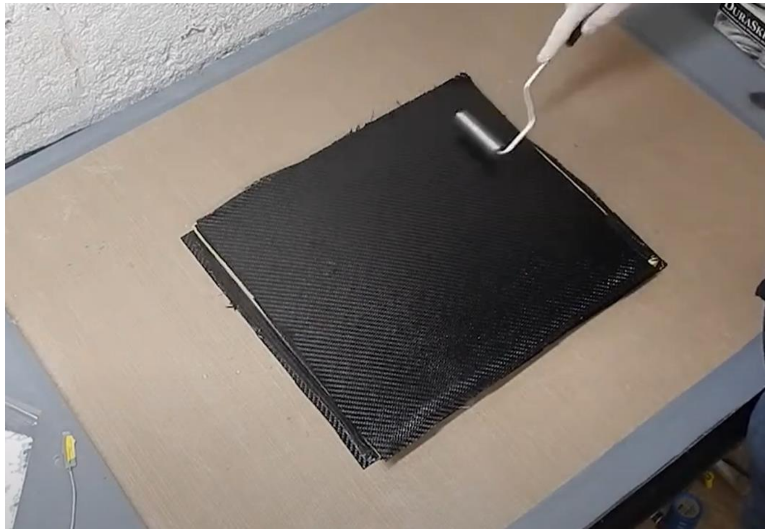


Image from the video showcasing the importance of rolling out air bubbles and avoiding oversaturation of the material with resin.

PRJ 1 #6

- An autoclave is a large machine that cures composites by simultaneously applying pressure and heat while under vacuum
- Vacuum is applied to remove air bubbles
  - Autoclave applies additional pressure of 30-100 psi to remove further void content
    - Usually applied using nitrogen gas
  - Too much pressure will ruin the resin content and result in uneven patches – too much pressure can squeeze out necessary resin for adhesion and polymerization
- Heat is applied to ensure resin flow is evenly dispersed throughout the structure
- The cure cycle is optimized - not to hot, not to cold - a balance between heat and pressure is necessary to maximize resin flow and polymerization
- Used in various industries – medical, automotive, aerospace, etc…
- Autoclave's can reduce production overhead, lower costs, and increase efficiency

Its like making a pizza!

PRJ 1 #7

- The spec sheets for IM7/8552 give us the following information
- **Classification** – Aerospace grade, automotive grade, medical grade, etc…
  - Material type – class, grade, and type
  - Industry standard & certifications – ASTM D3039, ASTM D790, etc…
  - Prepreg classification
  - Curing and processing classification – temperature, pressure, time, autoclave or oven, curing cycle
  - Recommended uses – where is the material compatible, where should it be used
- **Mechanical properties**
  - Tensile strength, modulus, compressive modulus, strain, shear strength, (at angles of 90 or 0 degrees) etc….
- **Physical properties**
  - Filament/weave count
  - Fiber density, fiber diameter, specific heat, resistivity, thermal conductivity of the material
  - Twist or not twisted
  - Resin content
  - Weight/length, cross-sectional area, yield
  - Available sizing
- Spec sheets help designers in selecting and utilizing the correct composites effectively, allowing them to make informed decisions
  - Provides design engineers without the need to write and maintain their own specification
  - Good for design engineers during PDR for hand calculations and estimations
    - Helps engineers understand the material and the specification that are associated with it
    - Spec sheets provide designer engineers with rough estimations and quick valuations to assist in the preliminary design of a structure, system, or component

PRJ 1 #8

- The spec sheets for AF191 give us the following information
  - Provides a product description – AF191 is a thermosetting epoxy adhesive film designed for high strength bonding in elevated temperatures
    - High fracture toughness and peel strength, excellent elevated temperature performance (350 F), flexible cure cycles (275 – 400 F), and available in different configurations (sprayable, isolated, unsupported, with lightweight conductive screens)
- Description of physical properties
  - Film weight and thicknesses in different configuration, defines the color, volatile content
- Product performance and mechanical properties
  - High temperature durability tests
  - Test temperatures on specific materials
  - Testing specific metal to metal contact, composite, honeycomb,
    - Stress, strain, overlap shear, modulus, humidity resistance
  - Shelf life and storage
  - How the product ages over time
  - Post cure cycles at different temperatures and how they perform
- Processing and application guidelines
  - The AF191 spec sheet focuses heavily on processing and application guidelines
    - Recommended cure temperature and cure times
    - Primer application
    - Surface preparation for optimal bonding
    - Metal to metal bonding
    - Composite bonding
    - Honeycomb structures bonding

- Shows designers how AF191 can be applied
- Temperature data allows for designers to check the suitability of the material for there use case
- Bonding requirements help designers decide based on their use case
- Ensures material computability with project specifications
  - AF191 spec sheet specially documents the effects of cure cycles at different temperatures
- Helps designers plan ahead and helps with eliminating excessive costs
- Storage and shelf-life data can prevent waste

PRJ 1 #9

- The spec sheets for Rohacell 200 WF give us the following information
  - Product overview and application
    - Closed-cell rigid foam designed for aerospace applications
    - Used for aircraft/aerospace structures – rotor blades, stringers, panels
  - Mechanical properties
    - Density (205 kg/m^3), compressive strength (9.0 MPa), tensile strength (6.8 MPa), shear strength (5.0 MPa), elastic modulus (350 MPa), shear modulus (150 MPa), strain at break (3.5%)
  - Thermal processing conditions
    - Processing at pressure up 0.7 MPa and temperatures up to 130° C – good for autoclave prepreg and resin infusion
    - Curing temperatures – up to 180° C
  - Manufacturing conditions
    - Easily thermoformed – good for complex shapes
    - Machinability – easy to shape during machining
  - Certification and standards
    - Every mechanical properties has its own standard associated with it
  - How its useful to engineers
    - This spec sheet has less data but is still useful for design engineers (its straight to the point)
    - Mechanical properties allow for calculation and estimation before moving forward in the design process
    - Good for optimizing a material selection and comparing to other types of materials
    - Manufacturing feasibility

PRJ 1 #10

- Background (Mid-1970s)
  - It was known that elevated temperature and high moisture content reduce the stiffness and strength of polymer-matrix composites
  - Research was conducted to study these hygrothermal effects
- Findings from Research
  - Moisture diffusion in polymers (polymer-matrix composites) follows Fick's Second Law
    - Fick's Second Law (1D Diffusion): $\partial m/\partial t = D\, \partial^2 m/\partial x^2$, where D is the coefficient of moisture diffusion
    - Once D is measured, moisture content can be calculated anywhere within the structure as a function of time based on
      - Initial conditions of the material
      - Surrounding environment (boundary conditions)
- Key Implications
  - Allows the calculation of
    - Measured coefficients of thermal and moisture expansion
    - Stress states within the structure as a continuous function of time
    - Decrease in composite material stiffness and strength due to increased temperature and moisture content
    - Significant deformations and stresses in many applications, including mechanical testing of composites
- Effects of Temperature & Moisture
  - Temperature changes occur in minutes (e.g., thick composites)
  - Moisture changes can take weeks to months
  - Moisture diffusion coefficient (D) is strongly influenced by temperature
    - Exposing composites to high temperatures accelerates moisture conditioning
    - High exposure temperatures create high moisture gradients, leading to stress gradients and potential microcracking
    - A tradeoff is required between moisture exposure time and structural integrity.

PRJ 1 #10 CONT.

- Testing & Conditioning Procedures
  - Large numbers of test coupons are simultaneously conditioned in environmental chambers at hygrothermal conditions
  - Conditioning temperature = mechanical testing temperature, as testing is often done above the boiling point of water
  - Moisture desorption and absorption follow Fick's Law, but specimen surfaces must not dry out during testing
    - Solution: Maintain the partial pressure of water vapor in the test environment equal to that of the conditioning environment
- Challenges in Testing High-Temperature & Moisture Conditions
  - For test temperatures higher than conditioning temperatures, testing must be conducted in a pressure chamber
  - Emerging concerns for components required to perform in hot and wet environments
    - Simulating hostile conditions in a controlled laboratory setting is critical
    - Certain apparatus loads may negatively influence results
      - Weight of grips suspended from the load cell
      - Chamber pressure pushing upward on the loading rod
      - Friction in the seal around the loading rod
    - These factors must be compensated for when reducing applied load vs. displacement data.

PRJ 1 #11

- The course objectives are the following
    - Understand the analysis and design of laminated composite structures
        - Various methods of manufacturing (hand lay-up, vacuum bagging, filament winding, autoclave, etc…)
        - Understand what makes up a composite (pre-preg, resin, fibers, fiber orientation, honeycomb structures etc.…)
        - Understand how fibers work (anisotropic vs. isotropic)
    - Experimental methods for the characterization of composite materials
        - Mechanics of composites, coupon testing, shearography, infrared techniques, x-ray
    - Failure criteria to predict failure of composite structures
        - How composite matrix works, analyze failures such as matrix cracking, fiber compression, etc…
    - Understand design considerations and application
        - Where is it okay to use composites? Where is it not okay to use composites?
        - How will it bond to other materials
        - Temperature considerations

PRJ 1 SOURCES

#7
https://ntrs.nasa.gov/api/citations/20200002400/downloads/20200002400.pdf
https://www.hexcel.com/user_area/content_media/raw/IM7_HexTow_DataSheet.pdf
https://hexcel.com/Innovation/Documents/Mechanical%20Characterization%20of%20Stretch%20Broken%20Carbon%20Fiber%20Materials.pdf
https://www.wichita.edu/industry_and_defense/NIAR/Research/hexcel-8552/8552-NCAMP-Process-Specification.pdf

$8
https://multimedia.3m.com/mws/media/241227O/3mtm-scotch-weldtm-structural-adhesive-film-af191.pdf

#9
https://pronatindustries.com/wp-content/uploads/2014/12/ROHACELL-WF-Product-Information-datasheet.pdf

#10
https://www.compositesworld.com/articles/composites-testing-at-elevated-temperature-and-moisture-content

BEGGINGING OF PROJECT 2

PRJ 2 #1

Types of Fibers/Resin

- Types of fibers included:
  - Glass Fiber:
    - Advantages:
      - Low cost
      - Corrosion resistance
      - Low-cost relative to other composites
    - Disadvantages:
      - Relatively low strength
      - High elongation
      - Moderate strength and weight
  - Carbon:
    - Advantages:
      - Hight stiffness
      - Great strength-to-weight ratio
      - Low density
      - Low thermal expansion
    - Disadvantages:
      - Vary in strength with processing
      - Brittle
      - Poor impact resistance

- Types of fibers included:
  - Aramid Fiber (Kevlar):
    - Advantages:
      - High impact resistance
      - Lightweight
    - Disadvantages:
      - Difficult to cut and machine
      - Absorbs moisture, can affect performance
      - low compressive strength
  - Natural Fibers (flax, hemp):
    - Advantages:
      - Renewable and eco-friendly
      - Lightweight
      - biodegradable
    - Disadvantages:
      - mechanical properties lower than synthetic fiber
      - Durability is affected due to moisture absorption
      - Can be affect to biological degradation

PRJ 2 #1 CONT. Types of Fibers/Resin

- Types of resins (matrix) included:
  - Thermosets: start out as liquids or paste-like solids and become rigid when cured. They can't be remelted once cured.
    - Epoxy Resin:
      - Advantages:
        - Shrinkage at a minimum during curing
        - Great mechanical properties
        - Resistance against chemical and environment
        - High adhesion to fibers
      - Disadvantages:
        - expensive
        - Requires precise mixing and curing conditions
        - Result can be brittle
    - Polyester Resin:
      - Advantages:
        - Cost effective
        - Easy to process
        - Good resistance to chemicals
      - Disadvantages:
        - lower strength compared to epoxy
        - More prone to cracking

- Vinyl Ester Resin
  - Advantages:
    - Affordable compared to epoxy
    - Better strength and toughness than polyester
  - Disadvantages:
    - More expensive than polyester resin
    - Requires precise curing conditons

PRJ 2 #1 CONT. Types of Fibers/Resin

- Types of resins (matrix) included:
  - Thermoplastics: can be melted and re-solidified when cooled
    - Polypropylene:
      - Advantages:
        - Lightweight
        - affordable
        - Good resistance to moisture and chemicals
      - Disadvantages:
        - lower strength compared to other thermosets
        - Poor adhesion to fibers
    - Polyetheretherketone (PEEK)
      - Advantages:
        - High stiffness and strength
        - Good impact resistance
        - Great temperature and chemical resistance
      - Disadvantages:
        - Very expensive
        - Difficult to process

PRJ 2 #2

- The manufacturing process of composites include the following
  - Preparation
    - Prepreg materials – which are impregnated with resin already by a manufacture in a controlled environment
    - Materials are cut and arranged in the desired orientation for the mold
  - Assembly
    - Prepreg layers are laid into the mold
    - A release agent is applied to the mold surface for easy part removal (silicone, salt solution, etc.)
    - Air pockets are evacuated, typically by massaging, using a squidgy, or by cold rolling
    - The entire assembly is sealed in a vacuum bag
      - Tape and or tack are used to seal the component in the vacuum bag to ensure no air gets released
  - Autoclave Setup
    - The vacuum bagged mold with prepreg is placed inside the autoclave, which serves as a pressure and heating vessel
    - Autoclaves come in different sizes, and can be adapted to material and manufacturing specification
  - Curing Process
    - The autoclave is heated and pressurized to the required levels
    - Heat and pressure cure the resin, bonding the fibers through polymerization and eliminating any air bubbles
    - The cure cycle is very delicate, and temperature control is very important to eliminate defects
      - To hot, the resin will escape the layup
      - To cold, the resin will not disperse evenly
  - Post-Curing
    - After autoclave curing, the composite part undergoes trimming, finishing, and quality inspection
    - NDI techniques are employed

PRJ 2 #2 CONT.

- The following supplies are needed to complete manufacturing in an autoclave setup
  - Prepreg material, unidirectional fabric, woven fabric
  - Resin
  - Application mold
  - Tooling
    - Roller, resin applicator, table – layup tools
    - Drills and post cure shaping/trimming tools
  - Vacuum bag and materials
    - Breather fabric
    - Peel ply
    - Tape
  - Release agent
  - Autoclave
  - Oven
  - Inspection equipment (NDI techniques)

PRJ 2 #3

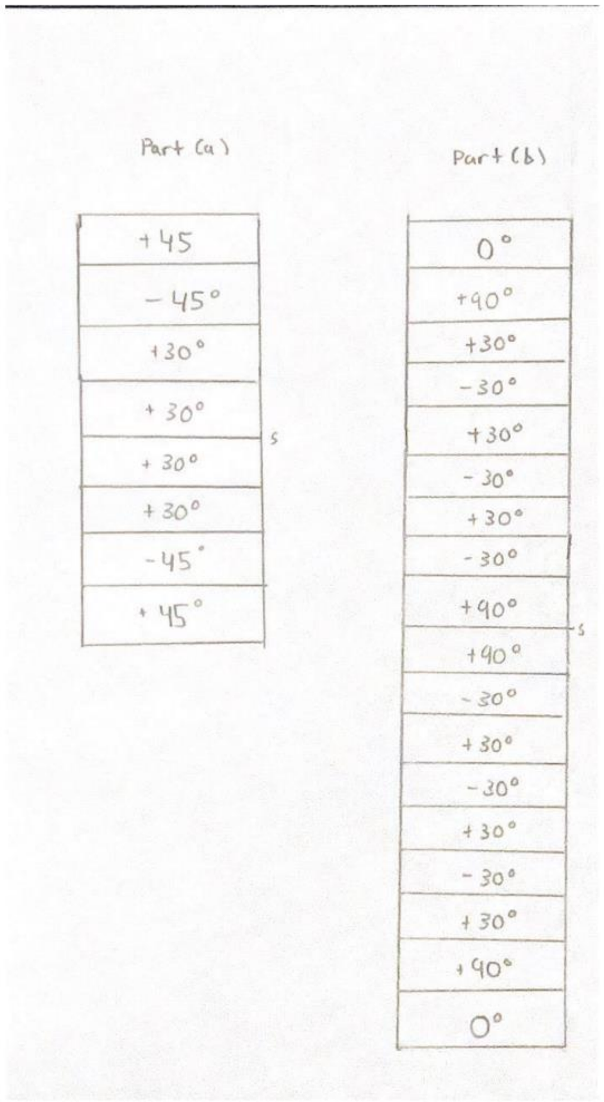
- 20 lessons learned
  1. Prepreg – pre-impregnated material, combines partial cured resin with fibers and must be refrigerated to inhibit further curing
  2. Prepreg simplifies and speeds composite layups, it also ensures higher quality parts
  3. Prepreg provides more consistent mechanical properties
  4. Reinforcement fibers and matrix are also available individually
  5. Wet layup is the most common manual way of making composites, thermosetting resins are more widely used than thermoplastic resins
  6. There is significant prep on molds to make sure the composite can be released from the mold; release agents are used (silicone, polyvinyl alcohol, fluorocarbons, water-based solvents)
  7. Gel coat resin applied to the mold can approve flexibility, stain resistance, toughness, and weatherability
  8. Reinforcement material (cloth) is impregnated with resin – “pre wetting”
  9. Pre wet material is hand rolled to remove entrapped air and achieve even distribution
  10. Automatic fiber placement machines were introduced to dispense prepreg on a mold surface
  11. Placement accuracy on these machines is within 0.005mm
  12. The automatic fiber placement machine are also extremely fast, speed ranges from 600 to 2400 inches
  13. Filament winding machines are computer numerically controlled (CNC)
  14. Filament winding machines can work with wet or dry strings
  15. Filament wet winding is the least costly option
  16. Pultrusion system consists of continuous fiber rovings that are unidirectional and only provide longitudinal tensile strength
  17. Suitable resins for pultrusion typically have low initial viscosity to ensure full fiber separation before impregnation
  18. Liquid molding uses special flow materials in vacuum to distribute resin through the component
  19. Sheet molding compounds consist of two layers of resin paste with a flat layer of chopped or unidirectional chopped fibers between
  20. Drilling is the most common machining operation applied to polymer matrix composite parts, drill speeds range from 2,000 – 25,000 rotations per minute

PRJ 2 #4

Diagram depicting the stacking sequence

A. $[45/-45/30_2]_s$

B. $[0/90/(+30/-30)_3\ /90]_s$



Stages in the Curing Process

- Stage A:
  - The materials are raw in basic form, where matrix is in liquid form for thermoset resin or in granular form in thermoplastic
- Stage B:
  - Both fibers and resin are combined in a single layer
  - For thermoset matrix composite appears semi-liquid so the sheet can hold the shape (prepreg)
  - For thermoplastic, the matrix is solidified
- Stage C:
  - Layers in Stage B are stacked on top of each other to make flat plate laminates
- Stage D:
  - Final product configuration is formed

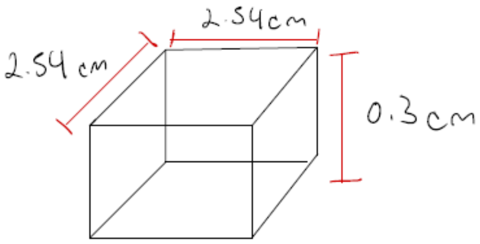
Curing : the drying and hardening (or polymerization) of the rein matrix of a finished composite. May be done unaided or by applying heat and/or pressure.

Failure Modes of Composites for Laminates and Sandwich Structures

- Failure Modes of Composites
  - Fiber Breakage
    - Occurs when the tensile, compressive, bending stresses exceed the strength of the reinforcing fibers causing fibers to fracture
  - Matrix-cracking
    - The formation and propagation of cracks in the polymeric, ceramic matrix that binds the reinforcing fiber together
  - Delamination
    - Layers of a laminated composite separate due to weak interlaminar bonding, can develop from mechanical, thermal, or environmental stresses
  - Ply-lifting
    - Individual plies (laminae) separate from adjacent layers and lift away from the composite structure
    - Associated with poor interlaminar bonding, residual stresses, thermal expansion and contraction as they cure
  - Crushing
    - The material undergoes localized compressive collapse, leading to fragmentation, densificaiton, and structural degradation
    - Involves high-energy impacts, compressive loading, protective gear, aerospace components

PRJ 2 #7

- Volumes and densities were calculated in the following work
    - The given information is located on the top right of the image
    - In order to solve for the volume fraction and the modulus, this was the first step



$W_{com} = 2.98\ g$

$W_{fiber} = 1.83g$

$\rho_{fiber} = 1.92\ g/cm^3$

$\rho_{resin} = 1.1\ g/cm^3$

fibers - $E = 40$ Msi

resin - $E = 0.5$ Msi

Density of comp

$V = lwh = (2.54 \cdot 2.54 \cdot 0.3) = 1.935\ cm^3$

$\rho = \frac{w}{V}$

$\rho_{com} = \frac{2.98g}{1.935cm} = 1.54\ g/cm^3$

Fiber

$V_{fiber} = \frac{w}{\rho}$

$V = \frac{1.83\cancel{g}}{1.92\ \cancel{g}/cm^3} = 0.953\ cm^3$

Resin

$W_{resin} = W_{comp} - W_{fiber}$

$2.98g - 1.83g$

$W_{resin} = 1.15\ g$

$V_{resin} = \frac{W_{resin}}{\rho_{resin}}$

$\frac{1.15\cancel{g}}{1.1\ \cancel{g}/cm^3} = 1.045$

$= 1.05\ cm^3$

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PRJ 2 #7

- The volume fraction of the fibers came out too
  - 0.54 or 54 % of the laminate
- The volume fraction of the epoxy came out too
  - 0.49 or 49 % of the laminate
- The volume fraction of the voids was then solved by subtraction which equaled
  - -0.03 or -3.0 %
  - We can assume this = 0
- The modulus along the fiber came out to
  - 19.87 Msi
- The modulus across the fiber came out to
  - 0.916 Msi

- The modulus calculations are in-line with common sense, fibers are anisotropic so the fibers along the laminate are much stronger. This is also told to us because the modulus along the fiber direction is 40 Msi, which means they are the load carrying fibers.
- Fibers dominate stiffness in the longitudinal direction

Volume fraction epoxy

$$V_{resin} = \frac{V_{resin}}{V_{comp}} = \frac{1.05\,\cancel{cm^3}}{1.935\,\cancel{cm^3}} = 0.54$$

$$V_{epoxy\ matrix} = 0.54 \text{ or } 54\%$$

Volume fraction fibers

$$V_{graphite} = \frac{V_{fiber}}{V_{com}} = \frac{0.953\,\cancel{cm^3}}{1.93\,\cancel{cm^3}}$$

$$V_{graphite} = 0.49 \text{ or } 49\%$$

Volume fraction of voids

$$V_{voids} = 1 - V_{epoxy} - V_{graphite} = 1 - 0.54 - 0.49$$

$$V_{voids} = -0.03$$

Modulus along fiber

$$E_{along} = E_{fiber}(V_{fiber\ graphite}) + (E_{resin}\ V_{epoxy})$$

$$(40\text{ Msi})(0.49) + (0.5\text{ Msi})(0.54)$$

$$E_{along\ lamina} = 19.87\text{ Msi}$$

Modulus across fiber

$$E = \frac{1}{\frac{V_{graphite}}{E_{fiber}} + \frac{V_{epoxy}}{E_{epoxy}}} = \frac{1}{0.49/40 + 0.54/0.5}$$

$$E_{across} = 0.916\text{ Msi}$$

PRJ 2 #8 Composites end markets: Sports and recreation (2025)

Composite Magazine Article: https://www.compositesworld.com/articles/composites-end-markets-sports-and-recreation-(2025)

- Composite materials have risen above other high-performance materials (e.g. titanium) in many elite sporting goods applications for their:
  - High strength-to-weight ratio (e.g. carbon fiber)
  - Vibration damping ability
  - Lack of corrosion issues
  - Ability to be tailored in the design and manufacturing process to meet very specific or custom requirements

- Ahead of 2024 Pari Olympics, watersports manufacturer Cobra International's carbon fiver composite surfboard
  - Are gaining popularity for their ability to reach higher speeds and better springback compared to fiberglass boards.

- Mel Composites showcased … (a distributor of custom foam, epoxy resins and consumables used in vacuum infusion
  - Padel rackets were displayed, demonstrating their latest materials and processing advancements in this field including new used of natural fiber composites and thermoplastics.

Composites end markets: Sports and recreation (2025)

•One example of a new sports equipment application for composite is modular, multi-material, multi-sport tracks manufactured by startup X-Track

- •Developed initially as a safer, more durable, easier-to-transport and -install alternative to traditional outdoor dirt tracks often used for bike and motocross racing
- •X-Track modules comprise an aluminum frame topped with a curved composite sandwich panel with integrated rubber surface material.
- •Composite panels are manufactured using adaptive molds, pre-shaped foam core and vacuum infusion
- •The complex shapes needed for racetrack modules, and the durability required to withstand repeated impacts from race vehicles, wouldn't be possible without composite materials

PRJ 2 #8

Composites end markets: Sports and recreation (2025)

- Bicycles: Developments toward thermoplastics, automation
    - Carbon fiber composite bicycle frames, particularly for high end sports bikes have become increasingly popular as the ultimate lightweight material option with high strength, natural vibration damping and no corrosion issued compared to metal bike frames
    - Global bicycle market size was $47.7 billion and expected to grow about 4% due to:
        - Rising fuel prices
        - Government programs building paths and roads
        - Increasing health concerns/fitness consciousness
        - Growing environmental awareness
        - Increasing traffic congestion

    - However many companies in North America and Europe have reported goals in the last few years of becoming more competitive in this space, including adoption of automated processes and thermoplastic composite (TPC) materials.

Prepreg Material & its Manufacturing Process

- A prepreg (pre-impregnated) composite material a fiber reinforcement that has been pre-impregnated with a thermosetting resin matrix or thermoplastic resin matrix
  - e.g. of fiber reinforcement (glass, carbon, aramid, etc.)
  - e.g. of thermosetting resin (epoxy, phenolic, polyester, etc.)
- Prepregs are used in many engineering and technology industries (automotive, aerospace, etc.) due to their high strength, lightweight, and superior mechanical properties
  - Require heat and pressure to full cure and often stored in cooling conditions to prevent premature curing

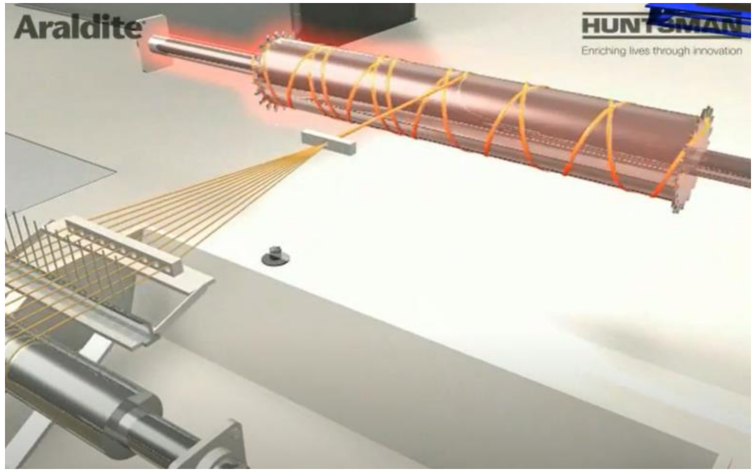
- To ensure uniform impregnation of resin into the fiber reinforcement, there are two methods for resin impregnation:
  - Solution Impregnation Method
    - Resin mixture dissolved in a solvent, reinforcing fibers passed through resin bath where they become fully impregnated
    - Passed though heated roller to remove excess resin and solvent
  - Hot-Melt Process
    - A resin film is spread onto a release paper with the reinforcing fiber laid on top of it where heat roller are passed to press fiber into the resin
- After removing excess resin and/or solvent, the resin-impregnated fiber would be dryed to remove excess wax and to allow the resin to cure
  - Can be cured by applying pressure and heat to the prepreg via autoclave
- Can then be cut into sheets or rolled into spools depending on the product or application

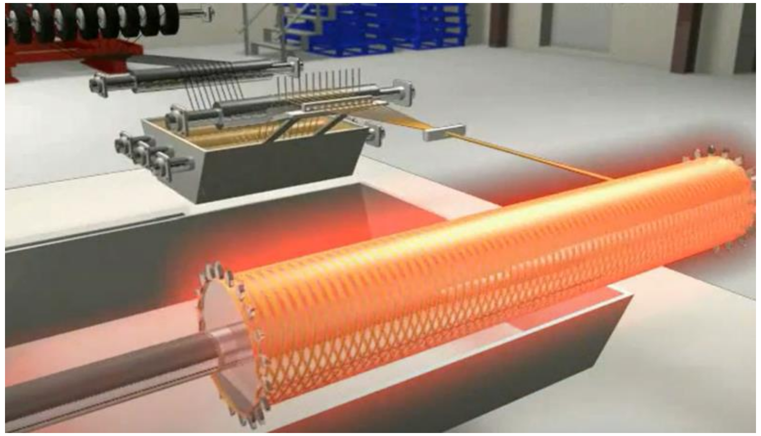
PRJ 2 #10 Advantages and Disadvantages with using Out-of-autoclave (OOA) Curing Procedures

- Advantages:
  - Often requires less expensive equipment compared to an autoclave, making it more accessible for smaller manufacturers
  - OOA allows for more complex geometries and larger parts that might not fit within an autoclave due to size constraints
  - Shorter cure times, leading to faster production rates
  - Utilizes lower pressure and heating requirements, that can lead to a total reduced energy usage.
- Disadvantages:
  - The quality of composites manufactured by this process is still inferior to those processed in the autoclave
  - Without a high pressure of an autoclave, OOA can increase the void content within the composite, affecting the component's mechanical properties
    - e.g. lower strength and stiffness
  - Limited on material options, not all composite prepregs and resin system are optimized for OOA curing, as some high-performance composites require that high pressure control that OOA curing does not offer
  - Composites are susceptible to environment (temperature, humidity, and vacuum leaks) that all lead to inconsistencies

Manufacturing of Composite Tube via Filament Winding

- Filament Winding of Composites Video: https://www.youtube.com/watch?v=ign6W5ENJAA
- Steps of Filament Winding per video:
  - Fibers are impregnated in a resin bath; they go through impregnation rolls and are spread
  - Impregnated yarns are wound around a mandrel by a lateral movement
  - Several lateral movements are made to achieve the desired thickness
  - Once the winding operation has been completed the yarns are cuts
  - The curing is induced by a heated mandrel and an infrared lamp
  - Once the tube is gelled, the mandrel is placed in an oven for cure
  - The pins are removed by sawing the edges and the finished tube demolded
- Advantages:
  - Automatic process for rotation symmetrical parts
  - Resin and fibers used in its lowest cost form
  - High mechanical performance achieved by:
    - Controllable fiber content
    - Straight fiber laying
    - Optimal fiber orientation based on external loads
- Disadvantages:
  - Production series limited
  - High investment costs (mandrels, machinery, ovens)
  - Limited to only convex shapes structures





Resin Transfer Molding

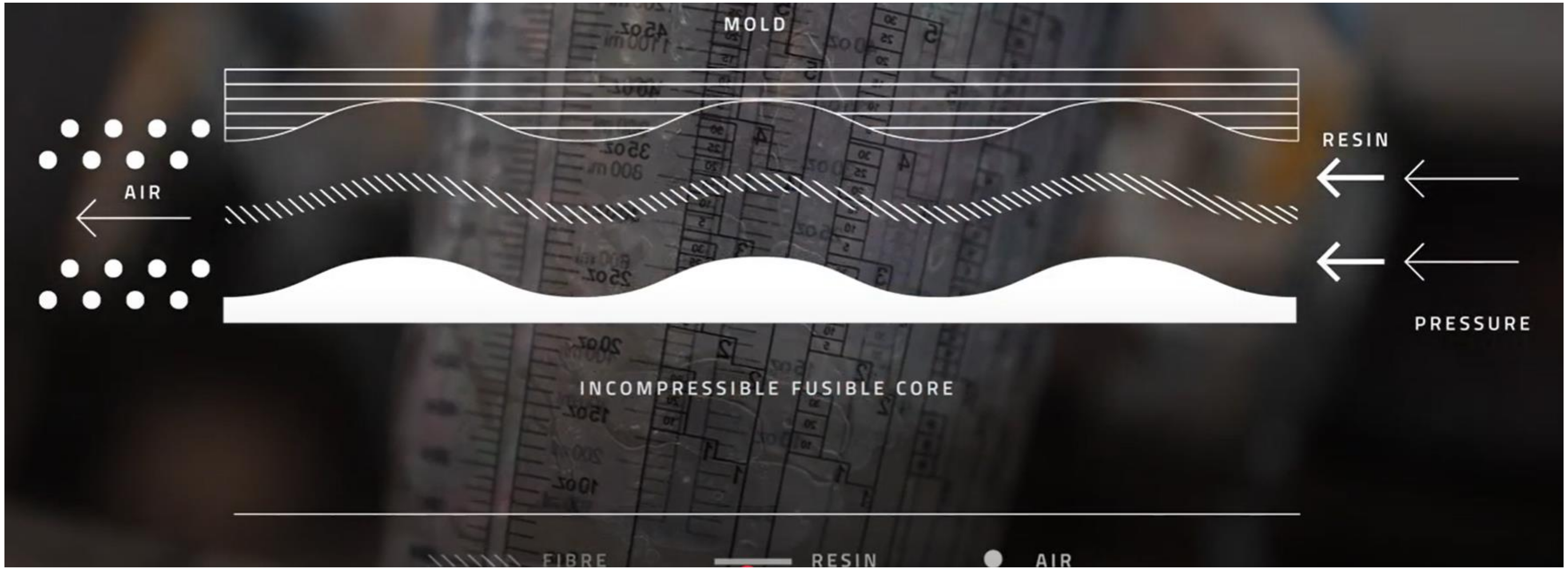
TIME Bicycles – Resin Transfer Molding : https://www.youtube.com/watch?v=kTEnPZFCjqA

- The Resin Transfer Molding (RTM) process is ever-present in aerospace and high-end automotive applications, however it's almost unheard of in cycling

The RTM process turns the soft, dry fiber frame layup into the solid, strong and flexible bike frame.

- This specific RTM process in the video greatly reduced the potential for defects withing the structure and enables them to create superior frames.
- After fibers are layered up and inserted into the mold, steel molds encase the frame to ensure an airtight seal.
- The resin is then prepared for injection into the mold, which is injected into the dry carbon under high pressure
- To avoid such high void content, air pockets are pushed out and voids between layers are eliminated ensuring complete wetting of the fiber

Resin Transfer Molding



- Excess resin flashing and steel inserts that ensure tolerances are removed from the frame

- One great and innovation thing about TIME Bicycles is that their internal wax molds are melted from inside the frame, which can then be recycled and re-used to create future molds (handlebar, fork, etc.)

Compression Molding

- Compression Molding Process – A Detailed Explanation: https://www.youtube.com/watch?v=FvzhutJ1H80

- Compression molding is a relatively simple process; involves pressing or squeezing a deformable material charge between two halves of a heated mold
    - Its transformation into a molded part is due to the cooling or curing process
- Typically, the raw material is heated before being added to a mold cavity
    - Raw material hardens while taking the form of the mold cavity as it cools
- Heat is often used in conjunction with pressure to facilitate the curing or melting of the material
- Compression molding is used mostly for molding thermosetting resins, but some thermoplastic parts may also be produced via this method
    - The method uses a split mold mounted in a hydraulic press
    - A pre-weighed amount of polymer mixed with additives and fillers is placed into the lower half of the mold
    - Before placement into the mold, the charge is usually preheated as it being preheated makes the charge softer, resulting in shorter molding cycle time.

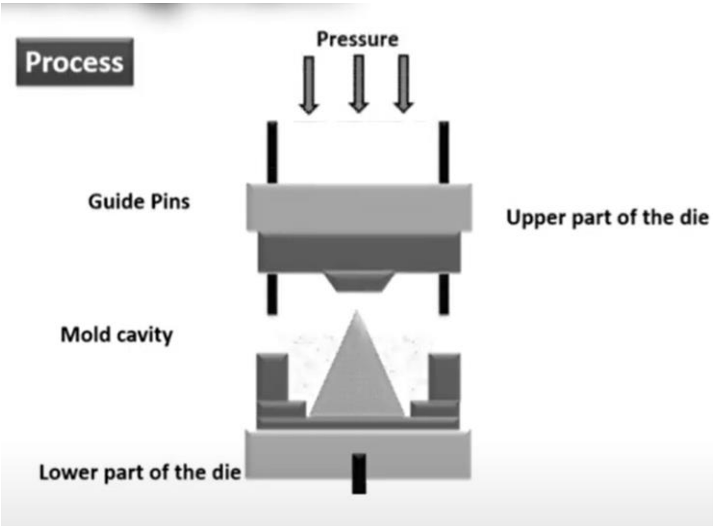
PRJ 2 #13

Compression Molding

- The upper half of the mold moves downwards, pressing on the polymer charge and forcing it to fill the mold cavity
  - The mold equipped with a heating system provides curing when thermosetting resins are processed
- Using the ejector pin, the mold can be opened, and the part can be removed

- If thermosetting resins are molded, the mold may be open in a hot state (still maintain their shape and dimensions even this state)

- If thermoplastics resins are molded, the mold and the molded parts are cooled down before opening



Compression Molding

- There are three types of compression mold designs:
  - Open flash type
    - The charge is overloaded, on closing the top and bottom platens, the excess material is forced out and the flash is formed
      - Produced lots of waste, creates minimal back pressure within the cavity, not recommended for parts requiring maximum density and strength
      - The parting line of the mold has a small gap
  - Fully positive type
    - The charge must be precisely measured
    - No allowance is made for placing excess powder in the cavity
      - The parting line of the mold does not leave any gaps, with excess, the mold will not close
    - Least waste and has greater part density control
    - The gas liberated during chemical curing reaction are trapped, may lead to blisters on the molded surface
  - Semi-positive type
    - Most expensive; features open flash and full positive molds; making some allowance for excess powder/flash
- Important factors to be considered when compression molding:
  - Amount of plastic charge, heating time, melting temp of plastic charge, pressure required, cooling time

Automatic Fiber Placement

- Automated Fiber Placement Process Optimization: https://www.youtube.com/watch?v=g_npBHtBcEE

- Automated Fiber Placement is all about increasing the manufacturing rate of composite components and increasing the reliability of the manufacturing process
- We can position layer of composite material accurately on complex geometries whilst keeping up with the aerospace industry demands.
- The Automated Fiber Placement technology is defined empirically through trial and error, still not a scientifically understood process.
  - Characterizing the materials that need to be process with AFP is crucial first step, to process and define the temperature and pressure
  - Afterwards, it would on the characterization of the manufacturing process: the parameters of the machine (heat and power), process parameters (temperature, pressure, force)
    - Combining the knowledge of the two, to check that they overlap, there will be a window of compliance where the material can be processed by the machine while meeting all other requirements
- Ex.
  - Characterizing the roller, which is used to lay up the material with an AFP machines to complex geometries. Testing with different roller and different compaction forces, one can computed how many tapes the machine should lay up.