Fiber reinforced composites

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Definition of Composites

- Composites merge distinct substances to create a highly durable, high-performance material with unique properties and a superior strength-to-weight ratio.

Key Characteristics:

- Distinct Phases: The constituent materials remain separate and identifiable within the finished structure.
- Matrix: The continuous phase (such as plastic or metal) that binds the materials together and protects the reinforcement.
- Reinforcement: The dispersed phase (like glass or carbon fibers) that adds strength, stiffness, and rigidity.

Fiber reinforced composites by PK Mallick
VACMOBILES

Types of composites

Metal Matrix (MMC)

Composition: A metal matrix (like aluminum or titanium) reinforced with fibers like silicon carbide.

Best For: Applications requiring high stiffness and resistance to severe heat.

Use Cases: Aerospace components and advanced automotive engine parts.

Ceramic Matrix (CMC)

Composition: A ceramic matrix reinforced with ceramic fibers.

Best For: Surviving brutal, extreme-temperature environments where metals would simply melt.

Use Cases: Jet engine turbines, rocket exhaust nozzles, and heat shields.

Polymer Matrix (PMC)

Composition: Plastic/polymer resin (epoxy, polyester) reinforced by glass or carbon fibers.

Why They Dominate: Massive strength-to-weight ratio, cheap, and easily scalable for manufacturing.

Use Cases: Wind turbine blades, airplane fuselages, boat hulls, and sporting goods.

Classification: Structural (PMC)

Laminates

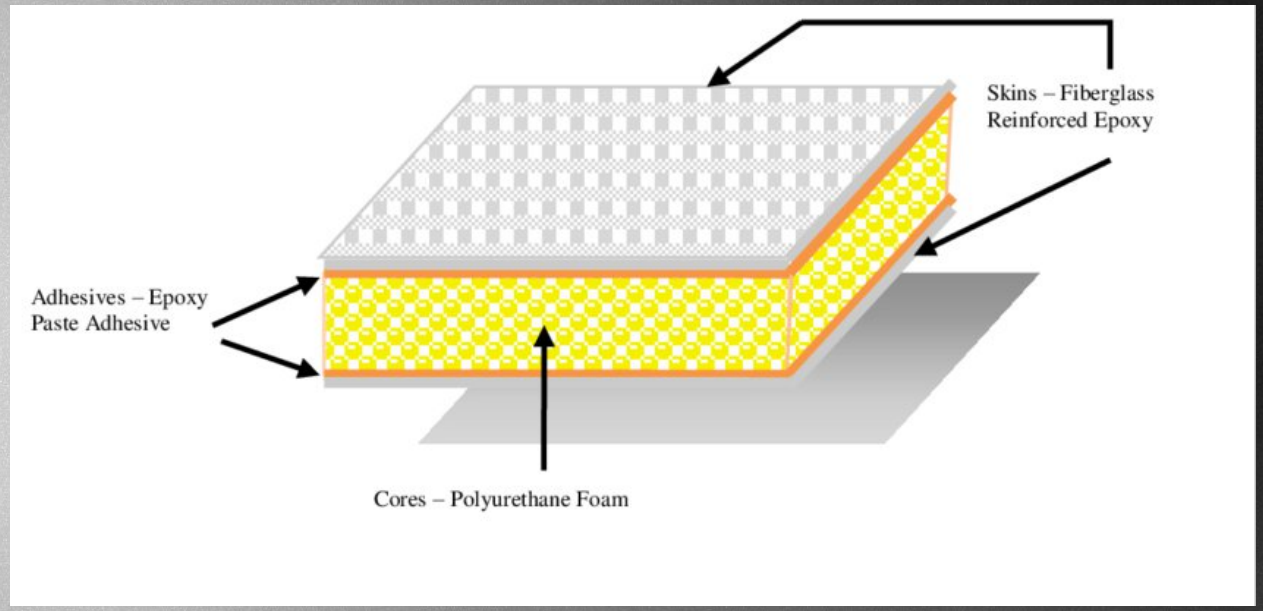
- Constructed from stacked and bonded fiber-reinforced sheets.
- **Stacking Sequence:** Sheets are layered at specific angles (e.g., **0° / 90°**) to handle targeted loads.
- **Primary Benefit:** This cross-directional stacking provides highly balanced in-plane stiffness and predictable strength.
- **Application:** Ideal for solid, load-bearing panels that require multi-directional durability.

Sandwich Panels

- A specialized construction prioritizing maximum stiffness with minimal weight.
- **Structure:** Consists of a thick, lightweight **honeycomb core** bonded between two thin, strong **face sheets** via an **adhesive layer**.
- **Benefits:** Delivers exceptionally low density combined with massively increased bending stiffness.
- **Real-World Uses:** Highly utilized in aircraft access doors, aerospace floor panels, and the hulls of super tankers.

Materials: The Structural Sandwich

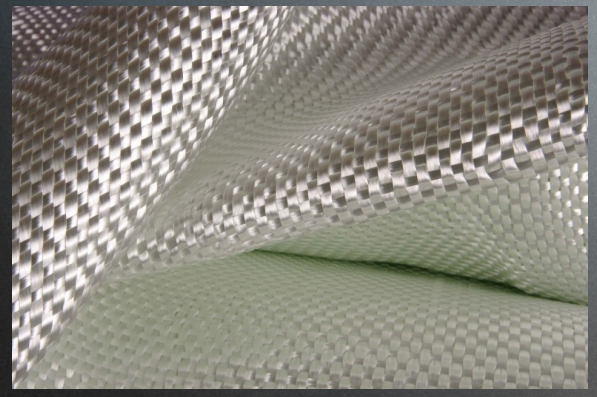
- A wind blade is built like a giant, high-tech sandwich. If you just used solid fiberglass, the blade would be far too heavy to turn efficiently. Instead, engineers use a "sandwich panel" design:
- **The Skins (Glass + Resin):** Thin layers of glass fiber cloth saturated in epoxy resin form the outer surfaces. These skins are incredibly strong in tension and compression—they handle the immense bending forces of the wind.
- **The Core:** A thick, lightweight material is placed between the two skins. This separates the skins, making the panel exponentially stiffer without adding significant weight, while also handling the "shear" forces trying to slide the skins past each other.



1.Glass Fabrics: The Reinforcement

Definition
The structural **"muscle" or skeleton** of the composite part. These are woven sheets made up of thousands of microscopic, ultra-strong glass strands.

Primary Use
Glass fabrics carry the physical load. They provide the material with immense **tensile strength** (resistance to being pulled apart) and excellent impact resistance.





Key Variations

E-Glass: The industry standard. Highly cost-effective and used in over 90% of everyday composite applications.

S-Glass: High-performance glass formulated for maximum strength and stiffness. Used heavily in aerospace and military applications.

Directional Weaves: Fibers aren't just woven like clothing; they are aligned in specific directions (e.g., Unidirectional or Biaxial) to handle stress coming from specific angles.

2. Resin

Definition
The liquid "**glue**" that saturates the dry glass fabrics and permanently cures (hardens) into a solid, rigid plastic.

Primary Use
Resin locks the delicate fibers in exactly the right shape. More importantly, it **transfers mechanical stress evenly** across the whole fabric and protects the glass from moisture, chemicals, and abrasion.

The "Big Three" Resins:

Epoxy: The ultimate in strength, adhesion, and durability. Cures with minimal shrinkage. Used for high-end aerospace parts, wind blades, and premium boats.
Vinyl Ester: The perfect middle ground. Offers superior chemical and water resistance. Ideal for harsh, corrosive environments like chemical tanks.
Polyester: The most common and economical resin. Fast curing and easy to use. Found in general-purpose parts like car panels and consumer goods.

3. Core Materials

Definition
A thick, lightweight filler material placed directly **between two outer layers** (skins) of fiberglass and resin to create a "Sandwich Panel."

The "I-Beam" Effect
By pushing the two strong fiberglass skins further apart with a core, you dramatically increase the part's **bending stiffness and rigidity** without adding the heavy weight of solid fiberglass.

Common Core Types

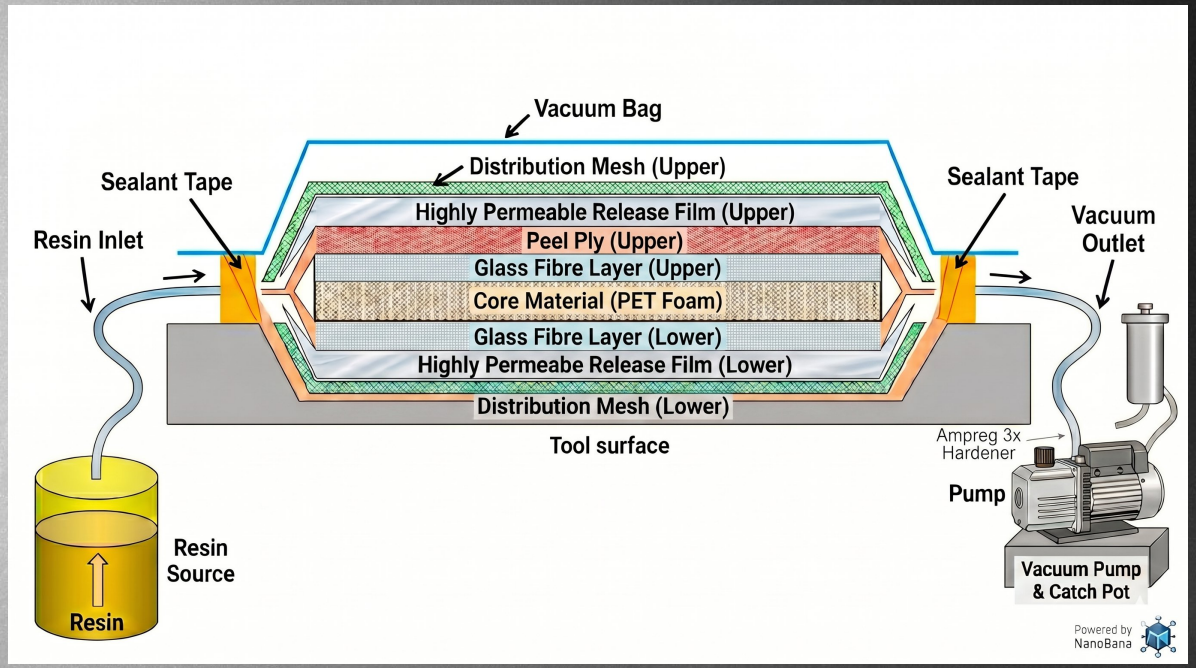
Structural Foam: High-density engineered foams (like PVC or PET). They are lightweight, resist absorbing resin, and are easily shaped into curves.
Balsa Wood: A natural, highly renewable wood core. It offers incredible shear strength, stiffness, and bonds exceptionally well with resin.
Honeycomb: Hexagonal cell structures (looking exactly like a beehive) made of aluminum or aramid paper. Used when absolute minimum weight is the top priority.

Process: Vacuum Resin Infusion

- VARTM Vacuum Assisted Resin Transfer Molding (VARTM), or the infusion process, is the industry standard for large, high-quality structures like aerospace frames and wind energy blades.
- Instead of manually painting wet resin onto fabric (which traps air), infusion relies entirely on atmospheric pressure.

- Why It's Superior

- Creates a highly consistent fiber-to-resin ratio across the entire part.
- Virtually eliminates air voids, maximizing structural integrity.
- Safer and cleaner manufacturing environment.



The VARTM Infusion Sequence

- The Vacuum Assisted Resin Transfer Molding (VARTM) process, commonly known as vacuum resin infusion, elegantly relies on atmospheric pressure to produce flawless, high-strength composite parts.
- It begins with a "dry layup," where glass fabrics and core materials are precisely stacked in a mold before the entire assembly is sealed beneath an airtight plastic bag equipped with specialized tubing.
- A pump then extracts all the internal air, causing the heavy atmospheric pressure outside to crush and tightly compact the dry materials together.
- Once a complete vacuum is confirmed, a valve is opened, allowing the vacuum to forcefully draw liquid resin through the compacted fibers; because the air was completely removed beforehand, the resin perfectly saturates the fabric without creating any structural voids or bubbles, ultimately curing into a rigid, highly durable composite structure ready for demolding.

Mechanical Testing: Validating Physical Limits

Why do we do this:

Because structures like wind turbine blades must endure 20 to 30 years of relentless aerodynamic forces, freezing rain, and blistering sun, they must be tested to their absolute breaking point before entering production.

Destructive Testing (DT)

Engineers cut small samples (called "coupons") from the excess composite material and place them in massive hydraulic machines to intentionally destroy them, gathering precise failure data.

Key Mechanical Tests

Tensile Testing: Pulling the material apart from both ends to measure its ultimate tensile strength (how much stretching force it can take before snapping).

Compressive Testing: Crushing the material to ensure the matrix (resin) can keep the fibers from buckling inward.

Fatigue Testing: Repeatedly bending the material millions of times over several weeks to simulate decades of continuous wind gusts and mechanical stress.

PET Foam Extrusion Process

Materials & Parameters

Composition
95% PET (Recycled/Virgin/Densified) combined with 5% Master Batch (Nucleating agent, Process Aid, Chain Extender).

Drying Rules
Moisture strictly capped, operating at elevated temperatures (125-150°C).

Blowing Agent(C5 H10,Cyclopentene)
Injected to dynamically generate the internal foam structure.

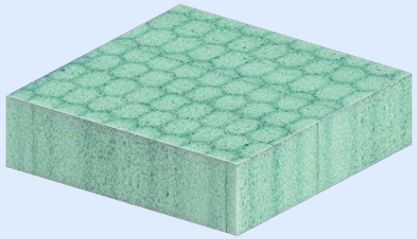
- **Key System Components:**

Twin Screw Extruder
Features two parallel screws that convey, mix (250-270°C), build pressure, and degas the PET.

Gear Box & Screen Changer
Transmits power precisely while filtering foreign particles for stable die pressure.

Calibrator
Controls dimensions, ensures surface flatness, and prevents deformation while the foam is soft.

Final Output
Kerdyn Green foam block, sliced, welded, and cured.

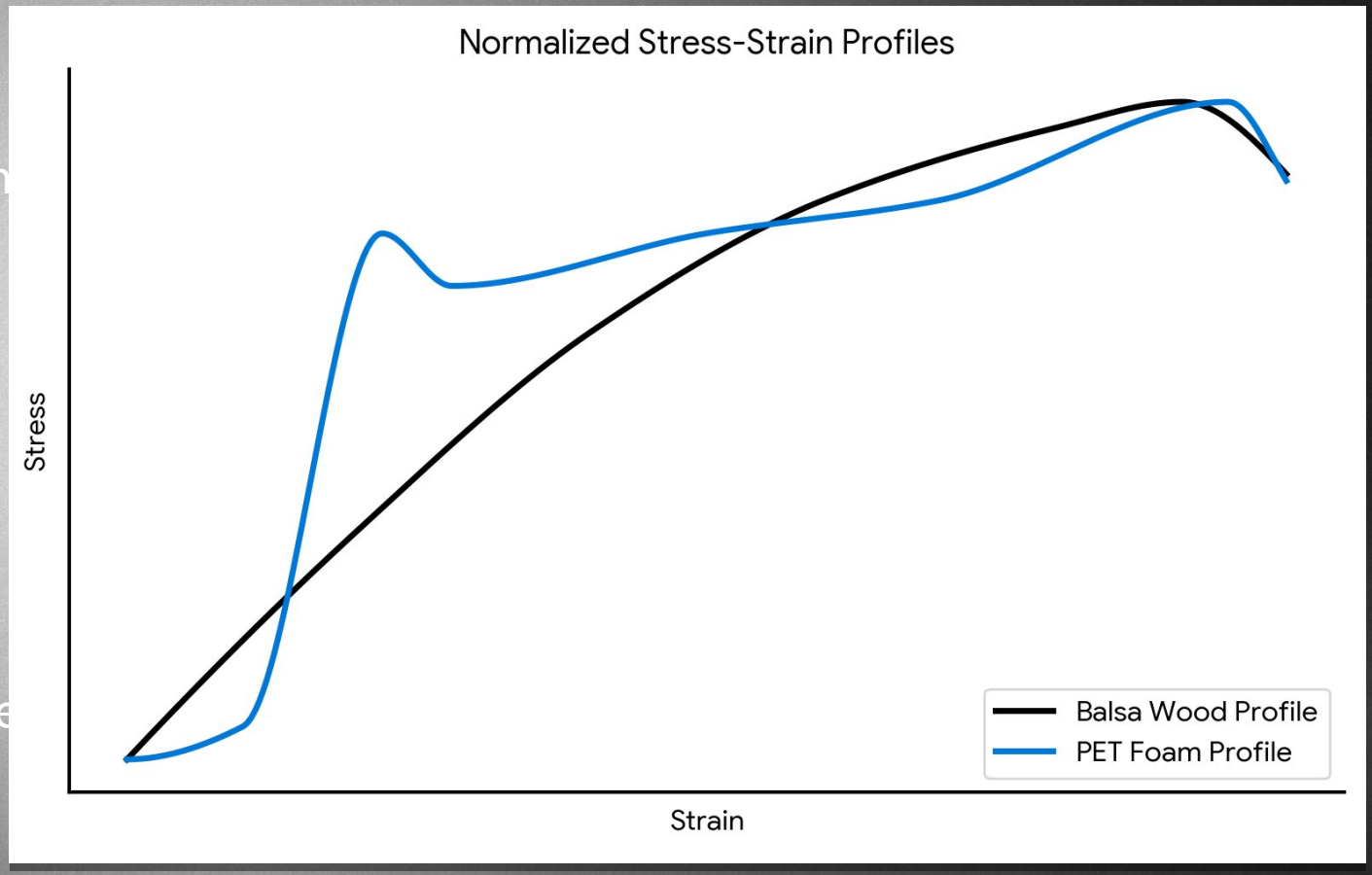


Compression Strength: Balsa vs. PET (IS0844)

- Balsa 150 (epoxy-infused) shows significantly higher compressive yield strength compared to PET Plank 100.

- Balsa 150 Yield Stress: 14.88 MPa
- PET Plank 100 Yield Stress: 1.21 MPa

- The balsa composite provides a ~12x increase in compressive load capacity over the PET foam.



Tensile Performance: Balsa Wood

- **Testing following ASTM C297 standards demonstrates robust tensile properties.**

Maximum Stress: 16.5 MPa

Young's Modulus: 2046.27 MPa

High stiffness-to-weight ratio suitable for high-stress structural applications.



Week 1&2 Summary

Day	What I Did	What I Learnt
1	I conducted an overview of composite materials, focusing on polymer matrix composites (PMC) and laminate structures.	I learned how sandwich panels utilize lightweight cores to exponentially increase bending stiffness without adding significant weight.
2	I studied the PET foam extrusion process, including material composition and key system components like twin-screw extruders.	I learned that moisture control and precise temperature management (250-270°C) are critical for maintaining PET structural integrity during extrusion.
3	I studied the mechanics of vacuum resin infusion and performed ASTM C297 tensile testing on balsa wood	I learned that balsa wood is very stiff and strong when pulled, with a Young's Modulus of 2046.27 MPa, making it excellent for parts that must handle heavy stress.
4	I observed compression testing comparing balsa wood composites against PET planks.	I learned that infused balsa wood provides a ~12x increase in compressive load capacity over PET foam
5	I completed observing the setup preparation for the full-scale vacuum resin infusion process.	I observed the workflow, including mold preparation, resin degassing to prevent pores, and atmospheric-driven infusion techniques.

Resin Uptake Analysis

- Resin Uptake analysis measures the volume and rate at which liquid resin is absorbed by a dry fiber perform. It tests the fabric's permeability and the resin's flow characteristics to ensure an optimal fiber to resin ratio, preventing structural defects like dry spots or excess component weight.
- **Methodology & Procedures:**

- Recorded mass measurements(length, width, thickness and mass) for samples both before and after the vacuum resin infusion process.
- Applied the following formula to determine resin uptake in kg/m^2

$$\text{Resin uptake} = \frac{Mass_{after}}{Length_{after}\ X\ Width_{after}} - \frac{Mass_{before}}{Length_{before} X\ Width_{before}}$$

Vacuum Resin Infusion (Hands on exp1)

Materials & Calculations

Component	Specifications (mm)
Bi-directional Glass Fiber (2 Layers)	200X200
Peel Ply	200x200
Release Film	200X200
Infusion Mesh (Upper/Lower)	200x200 / 300X200
Vacuum Bag	800x1500

Calculating GSM of the glass fiber:

Weight of glass fabrics = 32.6g
Size of the glass fabric= 0.2X0.2 m^2
GSM = $\frac{32.6}{0.2X0.2}$ = ~800 gsm

Calculating the resin required:

Number of layers=4
Length= 0.2m; Width= 0.2m; GSM=800
Resin required =0.2X0.2X4X800= 128g
Buffer(considering hose pipe, consumables) = 72g
Ratio of Resin to Hardener= 0.29
Total = 200 + (200 X 0.29)
Total= 258g

Procedural Execution

1. **Surface Preparation**
   Wipe the mold thoroughly with acetone to eliminate dust and grease ensuring a flawless finish.

2. **Mold Demarcation**
   Apply paper tape strategically to clearly define the exact boundaries of the working mold area.

3. **Releasing Agent**
   Coat the defined area evenly with NC55 to ensure a clean and uncompromised demolding process.

4. **Dry layup**
   Symmetrically stack the mesh, release film, peel ply, and the 4 layers of bi-directional glass fiber, peel ply, release film, mesh

5. **Vacuum Bagging**
   Enclose the setup with a vacuum bag and seal the perimeter tightly with sealant tape to prevent air leaks.

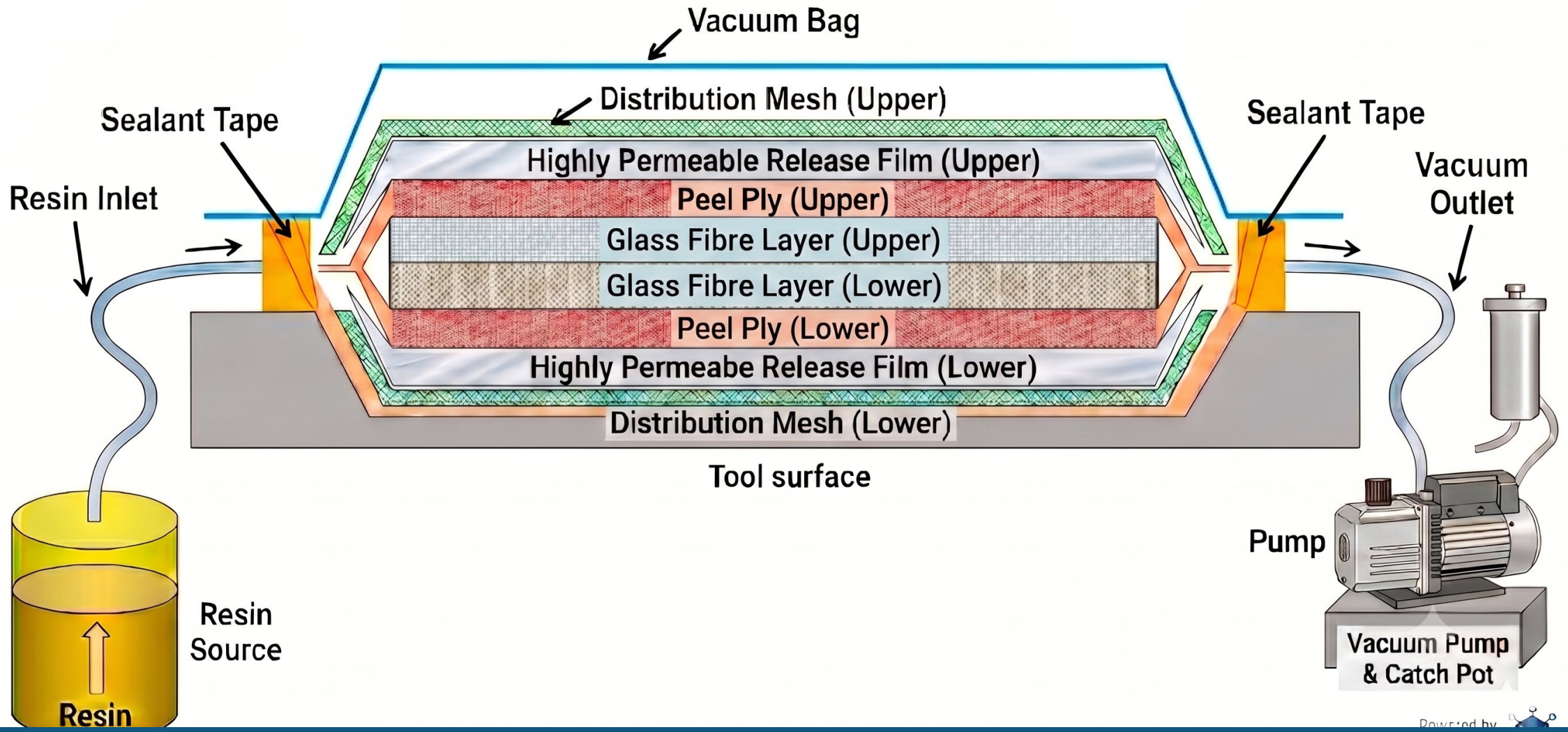
6. **Integrity Test**
   Perform a vacuum drop test, monitoring pressure to confirm a 100% airtight seal before proceeding.

7. **Resin Preparation**
   Mix Prime 37 Epoxy and Ampreg 3X Hardener precisely at the calculated 100:29 weight ratio.

8. **Degassing Cycle**
   Place the mixed resin system in a vacuum chamber for 5 minutes to extract trapped air bubbles.

9. **Resin Infusion**
   Unclamp the feed line, using atmospheric pressure to steadily draw resin through the dry stack.

10. **Thermal Curing**
    Transfer the infused, sealed setup to a hot oven to accelerate thermal curing and cross-linking.


Vacuum Bag
Distribution Mesh (Upper)
Sealant Tape
Sealant Tape
Highly Permeable Release Film (Upper)
Resin Inlet
Peel Ply (Upper)
Vacuum Outlet
Glass Fibre Layer (Upper)
Glass Fibre Layer (Lower)
Peel Ply (Lower)
Highly Permeabe Release Film (Lower)
Distribution Mesh (Lower)
Tool surface
Pump
Resin
Resin Source
Vacuum Pump & Catch Pot

Observation and Suggestion for improvement in exp1

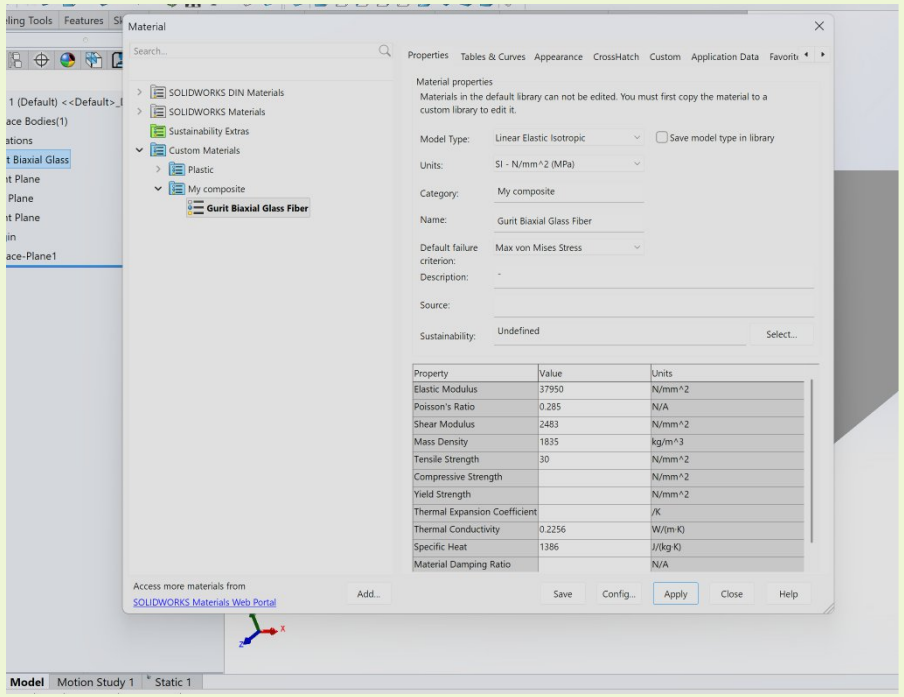
- **Observation:**
  - Consumables were not cut accurately to size.
  - Excess area was used for mold preparation.
  - Air bubbles were present in the final laminate.
  - The resin flow front was uneven during the infusion.

- **Suggestions for improvement:**
  - Use precise dimensional templates to cut all consumables
  - Leave a smaller border around the part to waste fewer materials and make the vacuum work better.
  - Remove air from the resin before starting, and hold a spare tube to your ear while tracing the tape lines to listen for hidden leaks.
  - Use a resin line clamp to slow the flow, giving the resin time to fully soak the fibers and push out trapped air.
  - Make sure the flow mesh is laid completely flat without wrinkles,and place your inlet and outlet tubes evenly.

Week 3 Summary

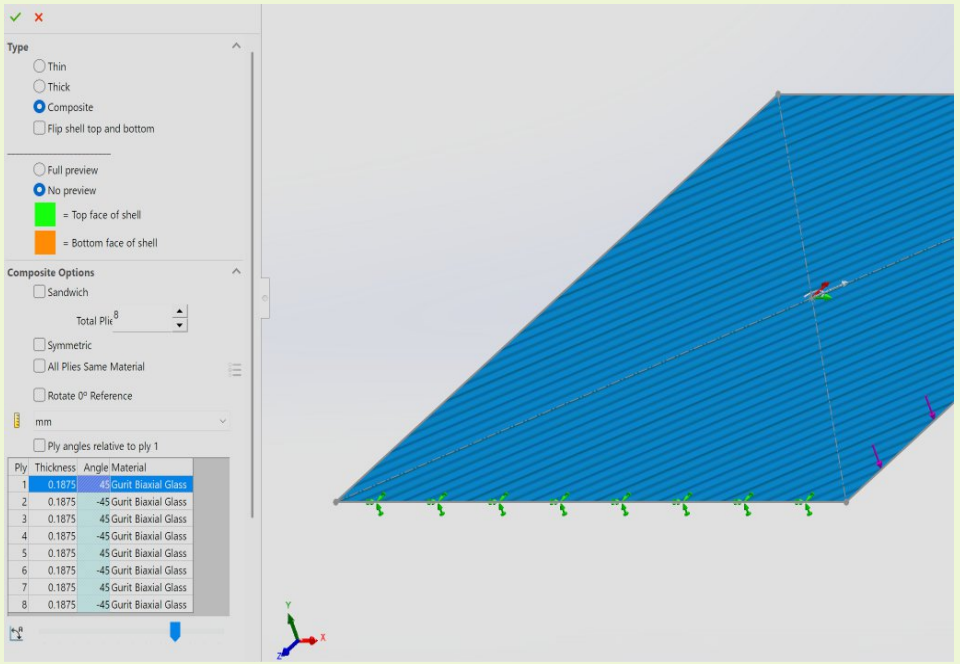
	What I Did	What I Learnt
1	I observed the procedure for calculating resin uptake by recording the mass, length, width, and thickness of samples both before and after the vacuum resin infusion process.	I learned that measuring resin uptake tests the fabric's permeability and resin flow characteristics to ensure an optimal fiber-to-resin ratio, which prevents defects like dry spots or excess weight.
2	I prepared the mold using acetone and NC55 releasing agent, then symmetrically stacked the dry layup materials (distribution mesh, release film, peel ply, and glass fiber layers).	I learned that thorough surface preparation eliminates grease for a flawless finish, and the specific symmetrical stacking sequence ensures proper resin distribution and an uncompromised demolding process.
3	I calculated the required resin for a 4-layer glass fiber setup using its GSM, factored in the buffer for consumables, and mixed the Prime 37 Epoxy and Ampreg 3X Hardener at a 100:29 weight ratio.	I learned how to accurately account for buffer amounts by considering the resin that will be lost to consumables like the hose pipe during the infusion process.
4	I enclosed the setup in a vacuum bag, performed a vacuum drop test to confirm an airtight seal, and degassed the mixed resin in a vacuum chamber for 5 minutes.	I learned that degassing the mixed resin system in a vacuum chamber for 5 minutes is a critical step to extract trapped air bubbles prior to infusion.
5	I analyzed the final laminate and identified that air bubbles were trapped and the consumables were not cut properly.	I learned that cutting materials accurately with templates and ensuring the correct quantity of resin are essential to prevent trapped air bubbles.

Simulation Of the Laminate



Geometry & Material

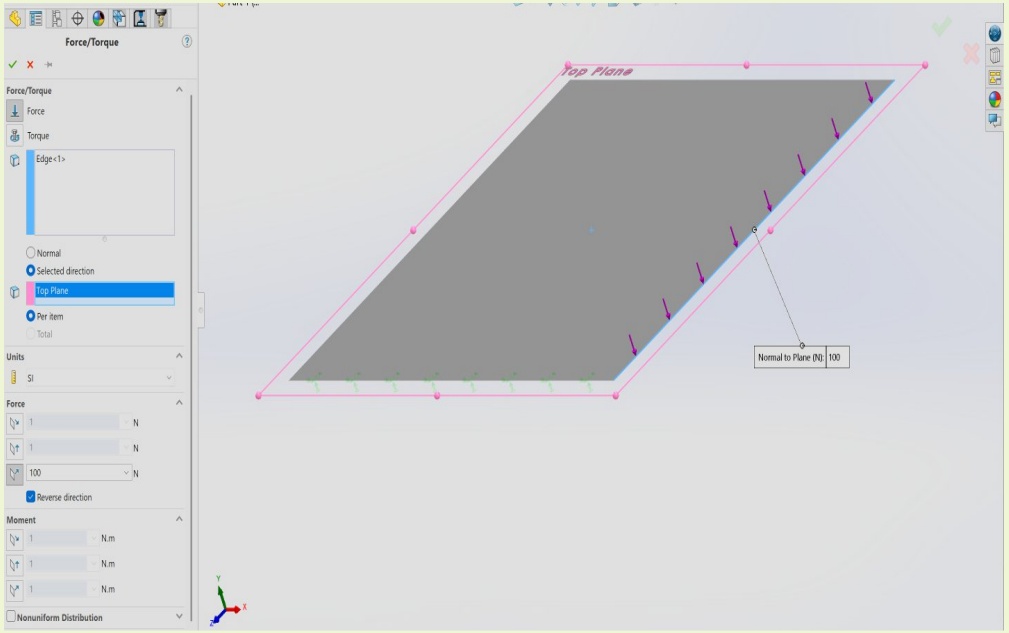
Modeled a 200 x 200 mm 2D surface. Assigned custom "Gurit Biaxial Glass Fiber" properties (calculated for 50% fiber volume).



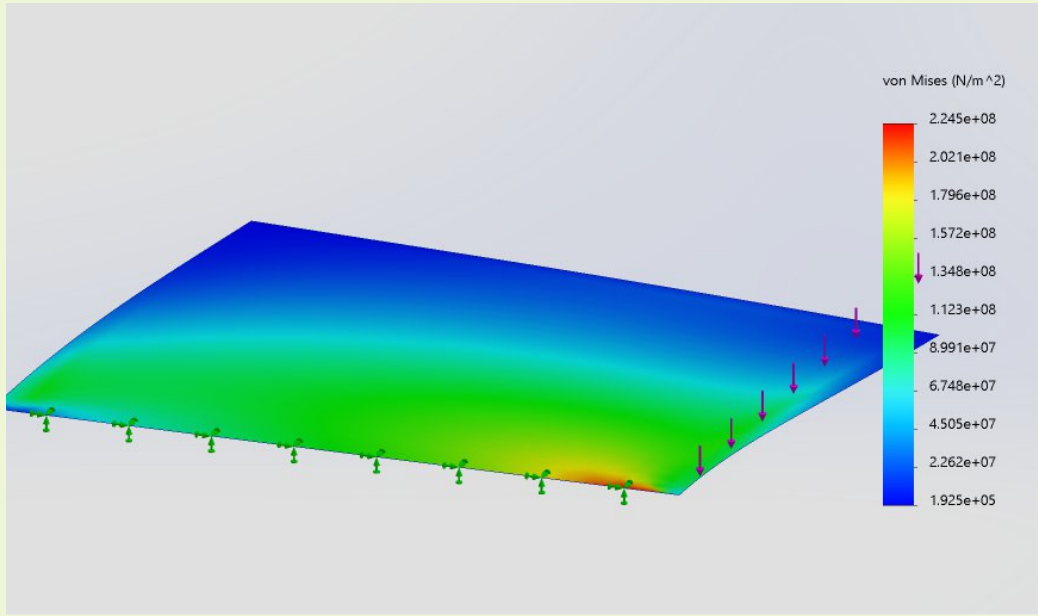
Composite Laminate

Converted 4 physical biaxial sheets into 8 mathematical plies (0.1875 mm each) applying alternating ±45° fiber angles.

Simulation Of the Laminate



Boundary Conditions Fixed Geometry:
Clamped one single edge to simulate a cantilever beam. Applied a 100 N downward force normal to the opposite edge.



Simulation Results
Ran static nodal stress analysis. Confirmed maximum stress (approx. 224.5 MPa) is localized safely at the clamped root.

Key Outcomes

- **Vacuum Infusion:** I learned the complete Vacuum Resin Infusion process, from dry layups to getting a perfect vacuum seal.
- **PET Foam Extrusion:** I observed the complete end-to-end process, starting from raw materials in silos and drying, through the extrusion phase where blowing agents are added. Finally, I tracked the material through the calibrator, curing, and final trimming phases for finishing.
- **Material Testing:** I observed stress, strain, and tensile testing to see exactly how much load core materials can handle before breaking.
- **Solving Problems:** I learned to fix infusion errors by cutting materials accurately,degassing and maintaing the resin percentage.
- **Simulation:** Modeled a custom 8-ply composite shell and performed structural Finite Element Analysis to evaluate how the laminate handles stress under a cantilever load.

Applications to Future Aerospace Engineering

- **Building My Designs:** I will use this hands-on experience to physically build the composite drone frames I design in SolidWorks.
- **Clubs & Competitions:** I will apply what I learned about composites and sandwich panels to build lighter, faster drones for my university engineering clubs.
- **Smarter Engineering:** I learned how to translate specific consumer requirements into lab tests to ensure their viability for large-scale manufacturing.