Composites for Buggy

9/28/24

Disclaimer: These slides are adapted from the Composites for Buggy course run on 9/28.

I have done my best to expand on these slides to include my speaker notes, but feel free to reach out with any questions or clarifications.

Opinions are my own and do not reflect any official position by Sweepstakes or the BAA.

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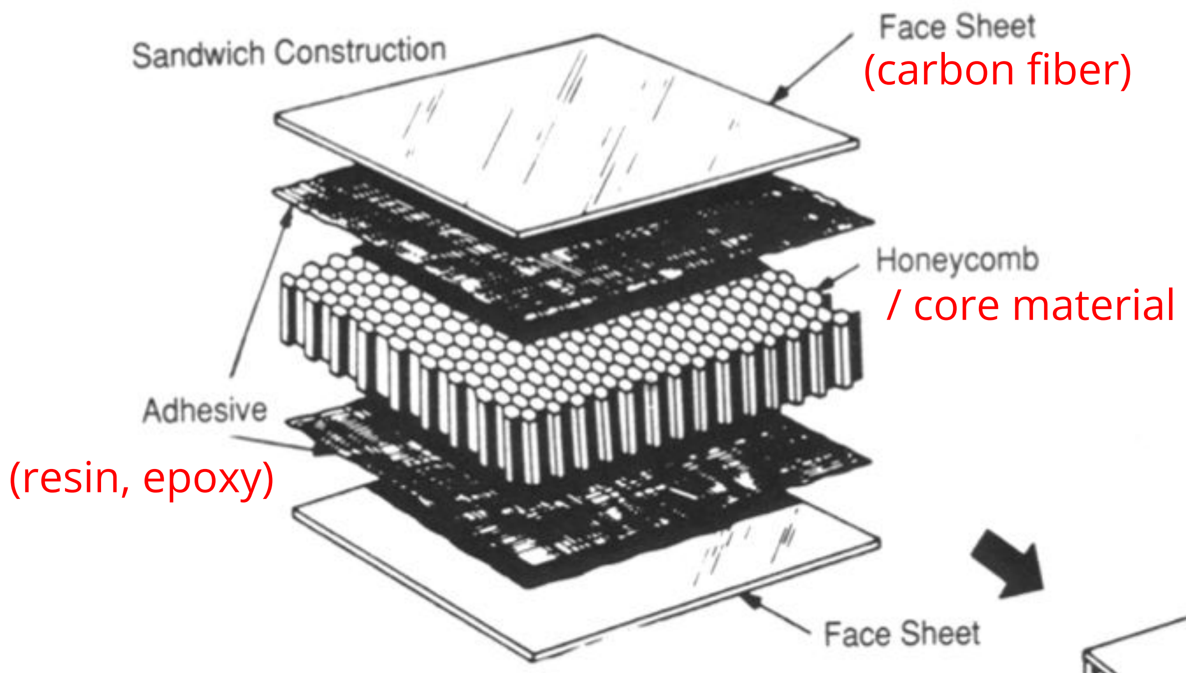
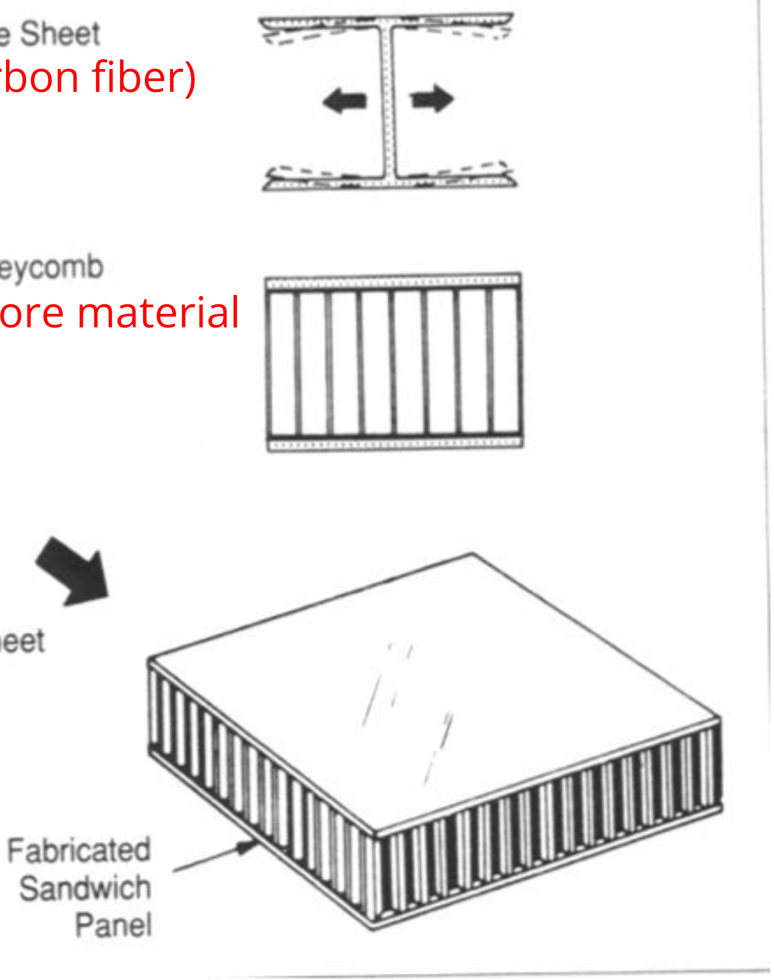
General outline

1 - What Are Composites?

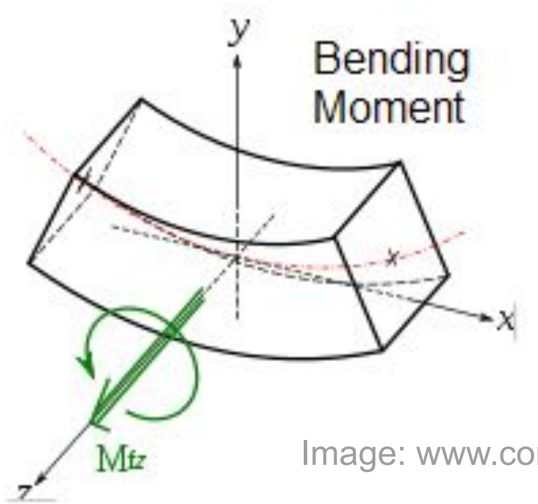




Exploded view of a composite sandwich construction: 3 major components: **face sheet, adhesive, core material**

Image: aerospaceengineeringblog.com/sandwich-panel/

Engineering Motivation



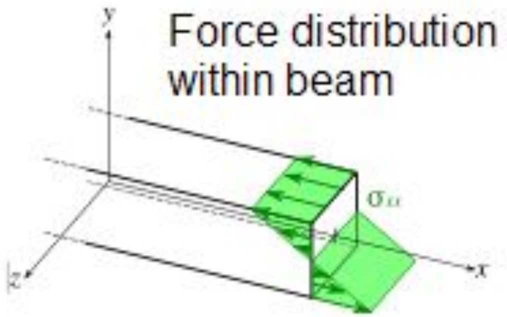
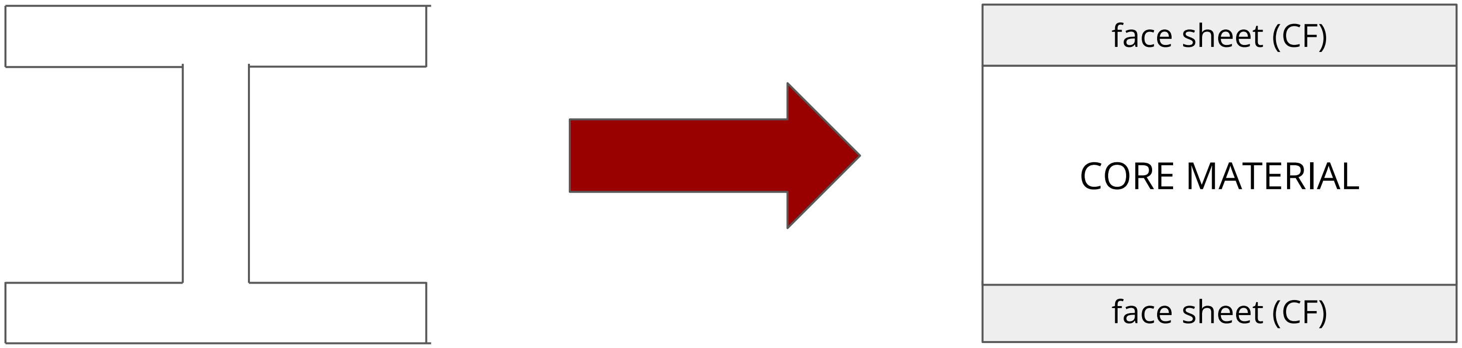


Image: www.coremarkmetals.com/hot-rolled-steel-junior-beam

When a part is in **bending**, the max stresses occur furthest from the centerline of the part (we call this the “neutral axis”).
The top of the part above is is in **compression** and the bottom is in **tension.**

Why do we use a sandwich structure?



We can think of a composite sandwich construction as an I-beam

The **face sheet** is usually a structural material, good under tension/compression.

The **core material** is usually a low density material, that isn't necessarily structural. It increases the stiffness of the sandwich by increasing width.

The **resin** bonds it all together.

2A - Material Selection

Carbon Fiber “Fabrics”

Search here... My account | 0 items

COMPOSITE ENVISIONS

Hexcel HiMax Carbon Fiber Fabric Biaxial +45/-45 Degree 12k 50"/127cm 4.42oz/150gsm T700 Fiber

SKU: F-1992-50

$36.39

1 Add to cart

Title	Range	Discount

What does literally any of this mean

Search here...

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COMPOSITE ENVISIONS

Hexcel HiMax Carbon Fiber Fabric Biaxial +45/-45 Degree 12k 50”/127cm 4.42oz/150gsm T700 Fiber

SKU: F-1992-50

Let’s break this down into 5 material selection criteria

$36.39

1 Add to cart

Title	Range	Discount

5 things to look at

(1) **Tow** (3K, 12K, 24K, etc)

(2) **Fabric weight** (GSM)

(3) **Construction** (woven vs NCF)

(4) **Fiber direction** (unidirectional, +/-45)

(5) **Fiber type/properties** (T300, T700, etc.)

1. Tow

“tow” = a bundle of carbon fiber filaments.
The number associated with tow (i.e. 3K) describes how many filaments are in each bundle

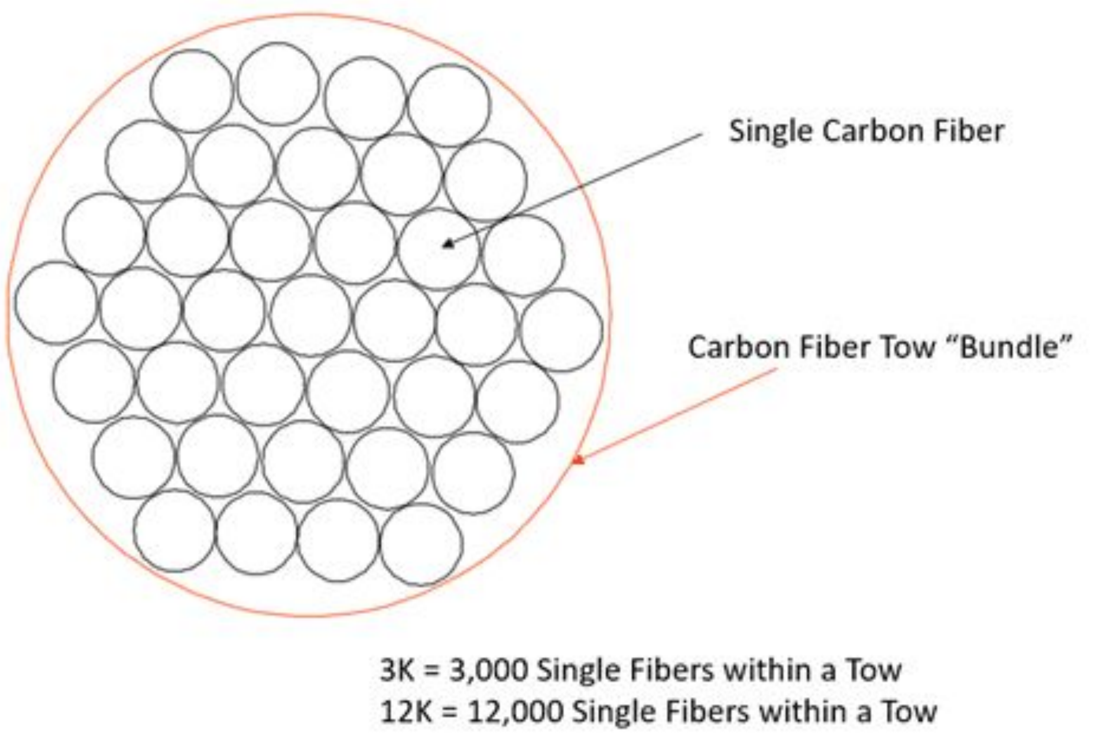


Image: https://compositeenvisions.com/document/what-is-1k-3k-6k-12k-denier-dtex/

1. Tow

So, does a higher tow # = heavier fabric? **NO.**

A couple reasons:

- Filaments may be different materials / specs with diff mass densities (ref criteria #5)
- Many fabrics are **"spread tow"** - tows are spread thin into thin "tapes" with a lower weight per area than non-spread tow. More on this when we get to construction.

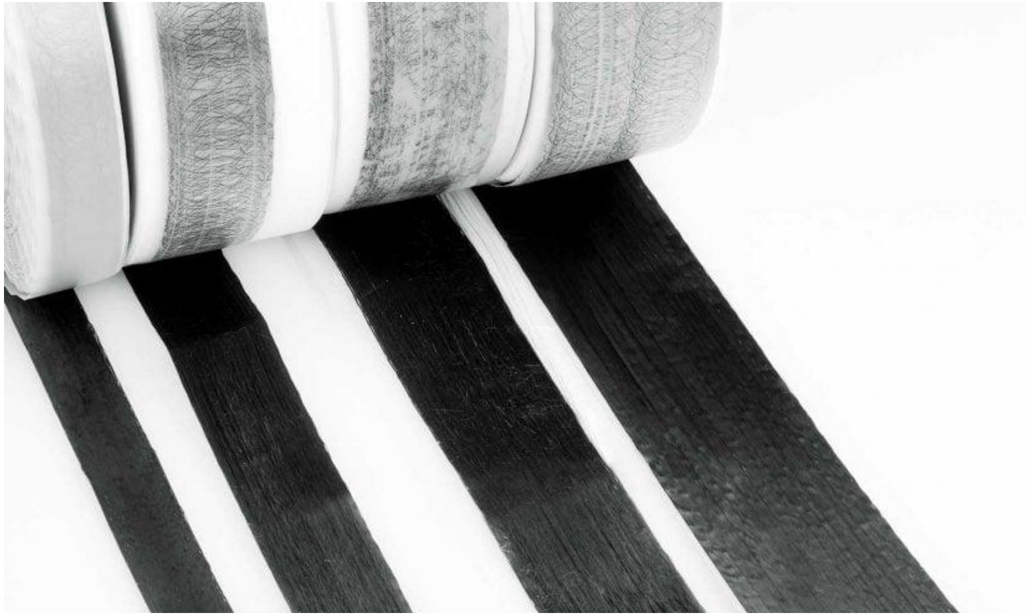


Image: https://www.textreme.com/product/tape/spread-tow-ud

Don't stress too much about this detail. The important part is tow ≠ weight

2. Fabric weight

GSM = Grams per square meter

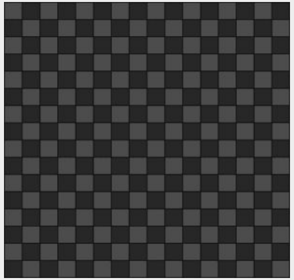
This will tell you the actual weight of the fabric (**not tow**)

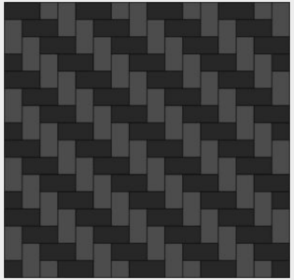
A carbon fiber with 12K tow can weigh 120gsm, 670gsm, or anything in between

3. Construction: Woven vs NCF

Woven

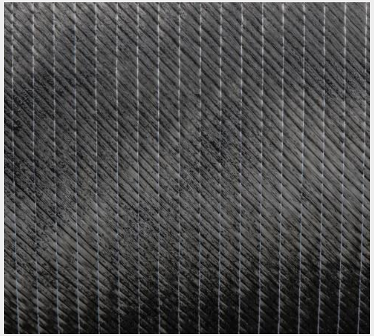
- Twill, Satin Weave, Plain Weave
- Tows are woven together (some variation of under/over pattern)





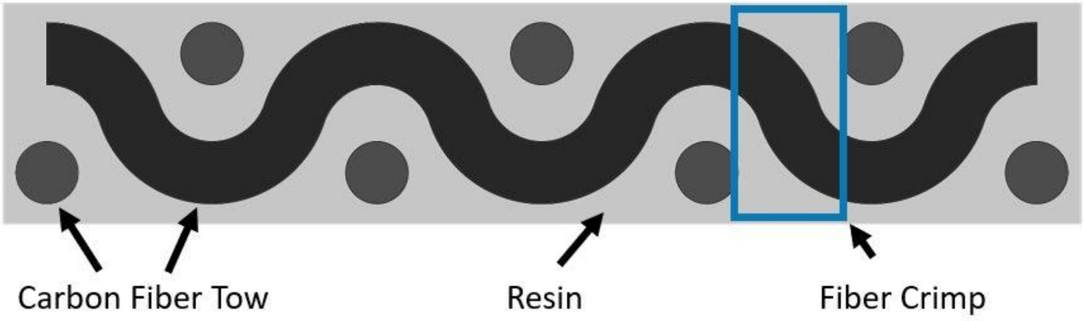
NCF / Stitched

- Non Crimp Multiaxial Fabric (NCF) - biaxial/triaxial
- Plies of uni-directional fabric are laid on top of each other and stitched together



Images: https://www.elevatedmaterials.com/carbon-fiber-weaves-what-they-are-and-why-to-use-them/

Pause– what is yarn crimp?



This is a cross section of a woven fabric, cut parallel to one set of tows. You can see the interlocking tows that weave over/under.
This creates a **crimp** - the tow changes direction and is oriented in/out of the plane rather than along the length of the composite.

Image: https://www.elevatedmaterials.com/carbon-fiber-weaves-what-they-are-and-why-to-use-them/

3. Construction: Woven Carbon Fibers

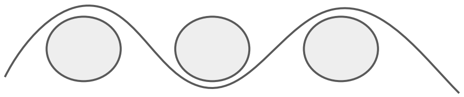
There are different weave constructions with varying properties.

Important properties we will look at:

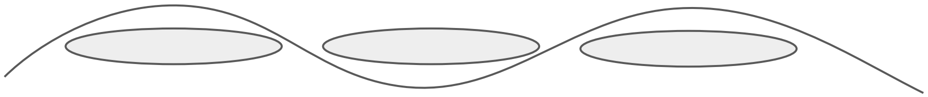
- Drapability (varies depending on weave, **but generally better than NCF**)
- Stability (varies depending on weave)
- **Crimp percentage** (varies depending on weave type, spread tows, etc)
    - results in Young's Modulus degradation

Spread tows will reduce "severity" of crimps:

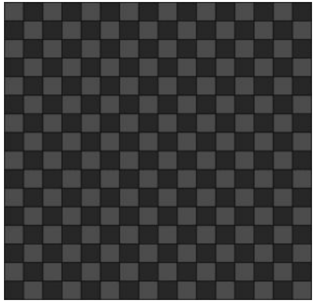
Standard tows:



Spread tows:



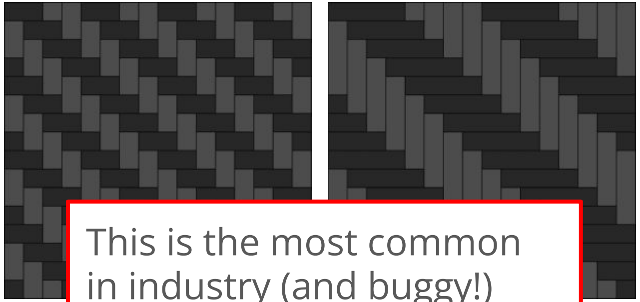
3. Construction: Woven Carbon Fibers



Plain Weave

Over 1, under 1

Harsh crimps
High stability
Ok drapability (2D curves)

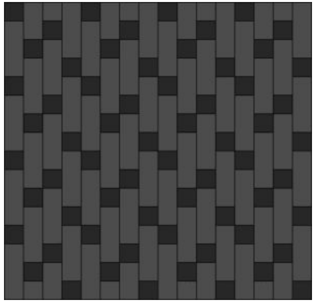


This is the most common in industry (and buggy!)

Twill Weave

nxn weave - over *n*, under *n*

Less harsh crimps
Slightly lower stability
Better drapability (3D curves)



Satin Weave

*n*HS - over n under 1

Least harsh crimps
Lowest stability
Best drapability (complex contours)

Images: https://www.elevatedmaterials.com/carbon-fiber-weaves-what-they-are-and-why-to-use-them/

3. Construction: Stitched (NCF) Carbon Fibers

Advantages:

No stress concentrations due to crimps– improves strength

Fiber directionality sometimes customizable

Generally heavier spread tows = 24K

Disadvantages:

Worse drapability, can be tough with 3D curves

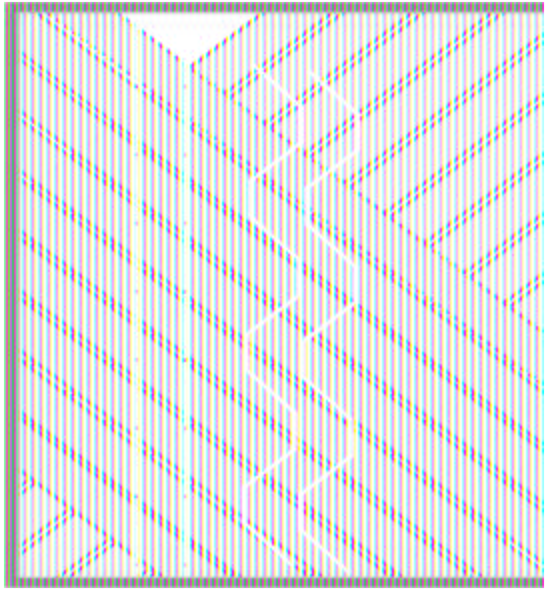
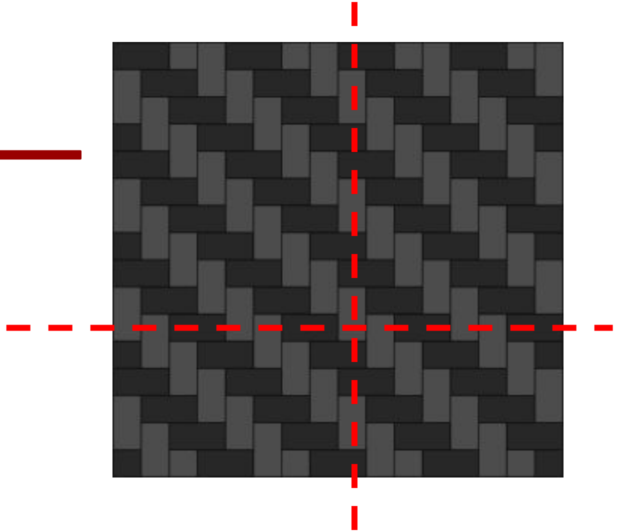


Image: https://www.multiaxialfabrics.com/carbon-fiber-biaxial-fabrics/?lang=en

4. Fiber direction



Carbon fiber is great under tension

You want fibers oriented **in the loading direction**

Unidirectional fabrics: fibers run in one direction

Bidirectional weaves: fibers are 90 degrees relative to each other (+/- 45)

Bidirectional NCFs: fibers are *generally* 90 degrees relative to each other

You can always layer plies

Images: https://www.elevatedmaterials.com/carbon-fiber-weaves-what-they-are-and-why-to-use-them/

5. Fiber Type / Properties

Different fiber types for different applications!!

We aren't going to talk specifics in this presentation, but here's a chart

note: this is from the Toray website and only includes Toray products

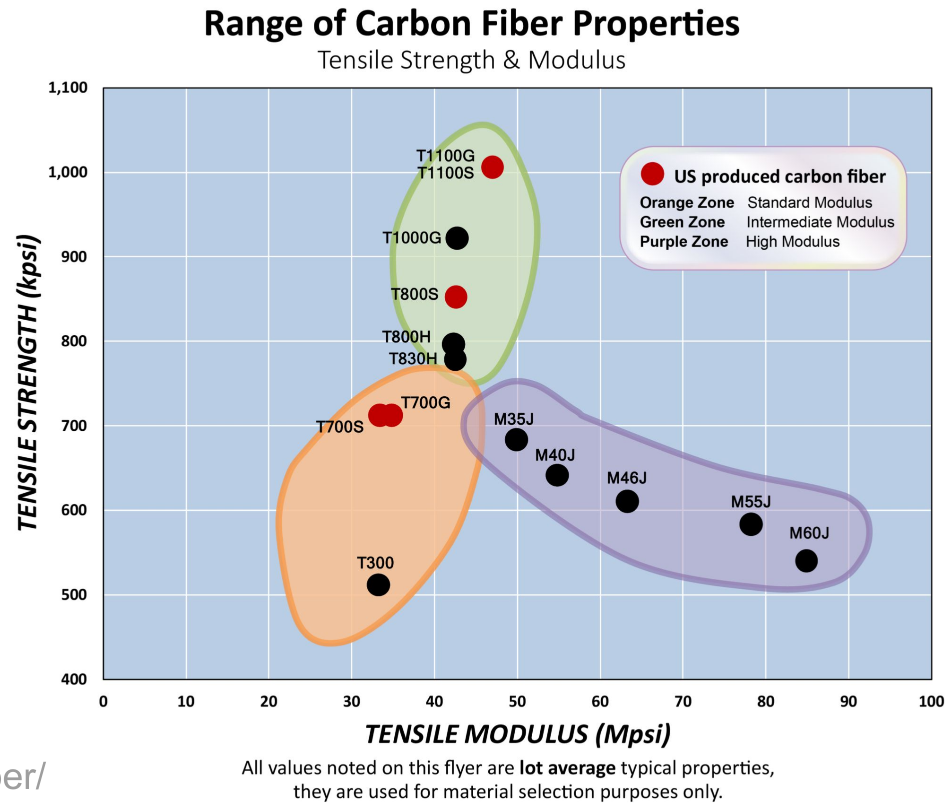


Image: https://www.toraycma.com/products/carbon-fiber/

2B - Material Selection

Core Materials

What to consider when choosing a core material

1. $$$
2. “Formability” - can I bend it to make the shape I want
3. Compatibility with your layup technique
4. Weight
5. Material Properties

Core materials

$$$** → **$

	Nomex (honeycomb)	**CoreLite PVC** (closed cell foam)	**Nidacore** (honeycomb)	**Balsa wood**
Formable to 3D curves?	Yes	No	Yes (with some effort)	No
Compatible layup techniques	Wet layup, prepreg	Wet layup, resin infusion, prepreg*	Wet layup, prepreg	Wet layup, resin infusion, prepreg*
Weight (kg/m^3)	29 - 64	40 - 250	80kg	~160
Compressive Strength (MPa)	0.9 - 2.9	0.5 - 6.5	1.2 - 2.6	~1MPa *(perpendicular to grain)*

* compatibility with prepreg will be based on your prepreg cure temp! More on this later.

Disclaimer: i made this chart and it is to some extent a vibes-based assessment

2C - Material Selection
Resins

What to consider when choosing an adhesive / resin

1. Material properties
2. Compatible processes (and fabrics)
3. Pot life (i.e. how long does it take to cure)?
4. Cost

Tip: For applications that experience particularly high or low temps, or long-term UV exposure, things like service temperatures and UV resistance will be a major consideration. For buggy, not so much. **Consider your application!**

Types of resins

- **Epoxy**
  - Best strength/stiffness properties
- Polyester
  - Longer layups (over multiple days), low viscosity, cheap
- Vinyl-ester
  - Chemical resistance

Process Considerations

Cure temperature

- Does the epoxy cure at room temp, or does it require heat / post-cure?
- Consider if your mold & core material can be subjected to heat

Viscosity:

- Low viscosity for resin infusion, higher viscosity for wet layups

Pot Life

Make sure you have time to finish your wraps!

In general – longer pot life for larger parts. You may be able to get away with 5min or 30min for small stuff– but not full shell!

3 - Layup Methods

Wet layups

Wet resin!

1. Precut carbon fiber (or other face sheet material)
2. Mix resin
3. Saturate your carbon fiber with resin
4. Apply the saturated carbon fiber to your mold (or your part) and make sure it lays correctly
5. Apply vacuum bagging materials (remember to smooth down your peel ply!)
6. Hook up and start your vacuum
7. Check back to make sure you're pulling a vacuum :)

Wet layups

+

Very little capital equipment required

Compatible with most possible core materials

(Generally) no need for specialized resin

Room temperature cure

−

Can be messy

Finesse work all happens under time pressure (epoxy pot life)

Quality (saturation, voids, etc) varies as this is a very manual process

Resin infusion

1. Precut carbon fiber (or other face sheet material)
2. Position carbon fiber into your mold, make relief cuts and smooth as needed
3. Apply vacuum bag & infusion consumables (smooth your peel ply!)
4. Hook up your vacuum and resin feed
5. Seal and pull down your vacuum bag - make sure vacuum is tight against all internal corners
6. Mix resin
7. Hook up your resin feed, and start infusion

Wet resin!

Resin infusion

+

Clean process, minimal handling of wet resin

Finesse work happens before epoxy is mixed, good for large parts

Uniform resin saturation, fewer voids than wet layups - stronger per weight

Room temperature cure

−

More capital equipment than wet layup, more expensive

Not compatible with some core materials (honeycomb)

Needs specialized resin

Prepreg

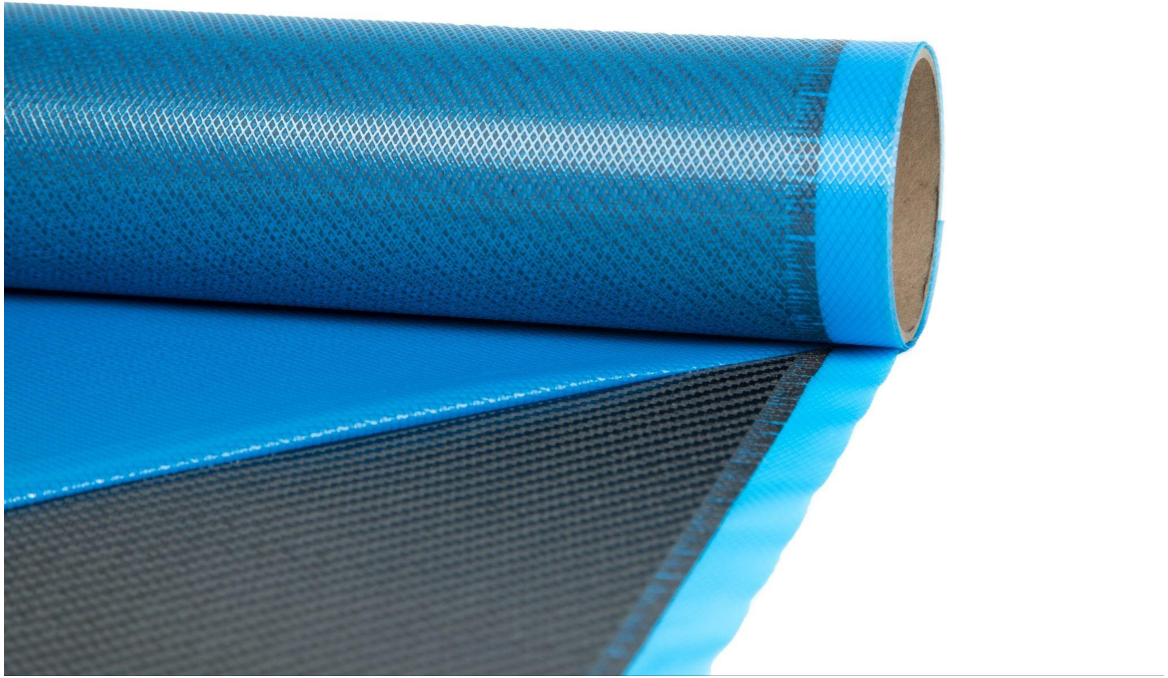


Image: https://www.heatcon.com/product/hcs2402-103-hexcel-carbon-fiber-prepreg-fabric/

Prepreg

1. Bring prepreg to room temp
2. Create cut templates from your part
3. Cut your prepreg
4. Remove backing and apply prepreg plies (“debulk” between plies is optional)
5. Oven cure

Prepreg

+

No working against pot life - resin will not cure until heated

Uniform resin saturation, fewer voids, generally best layup quality - strongest per weight

−

LOTS of capital equipment needed

Prepreg is more expensive than non-prepreg CF

Storage requirements

Requires heat to cure

Not compatible with all mold and core materials (heat)

Ways to form your part

Do nothing

Vacuum bag

Compression molding

(We aren't going to talk about the "do nothing" option because that's pretty self explanatory– and not recommended. Sorry).

Ways to form your part

Do nothing

Vacuum bag

Compression molding

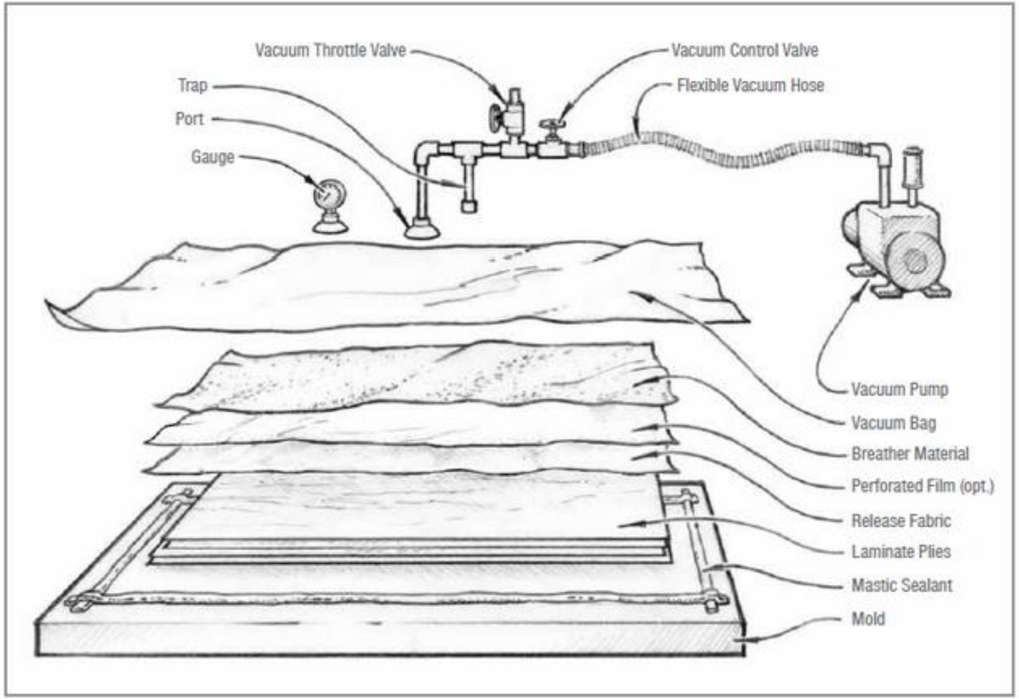


Image: https://www.epoxyworks.com/vacuum-bagging-basics/

Ways to form your part

Do nothing

Vacuum bag

Compression molding

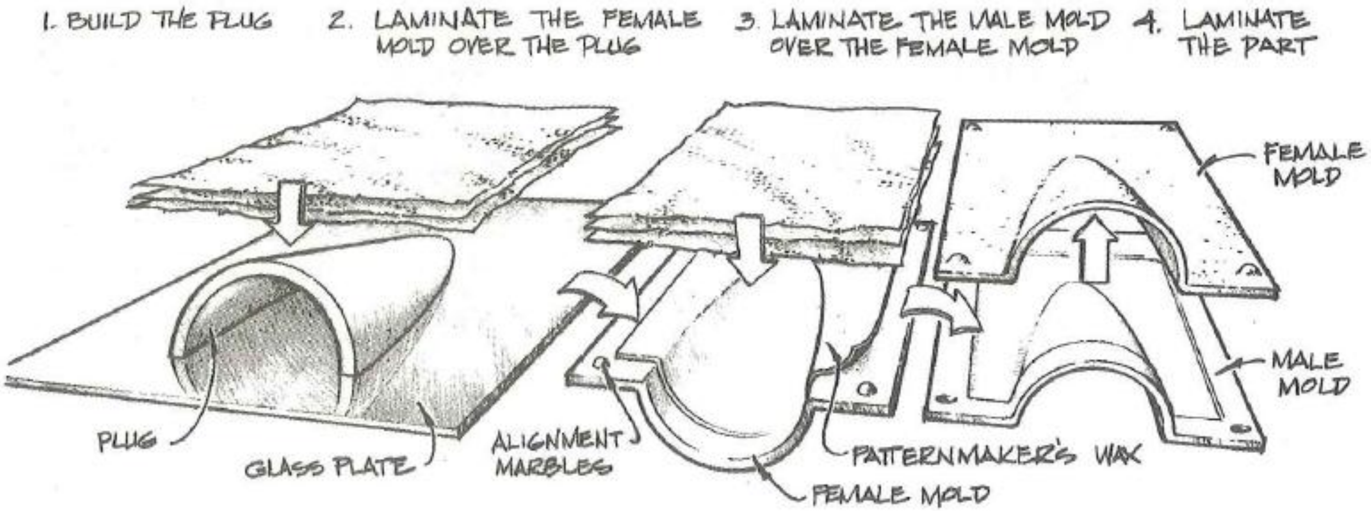
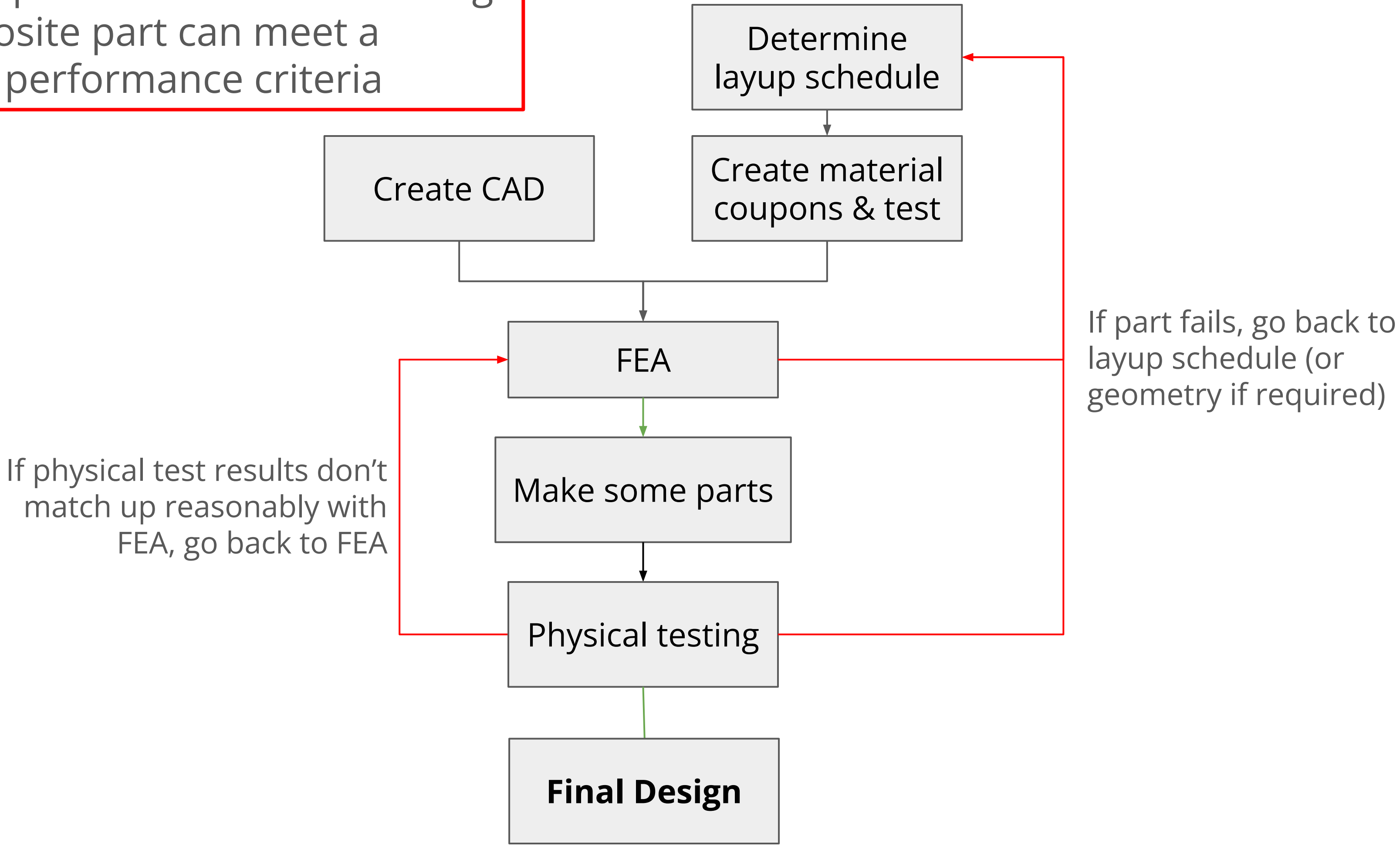


Image: https://www.epoxyworks.com/producing-parts-in-a-matched-mold/

4 - Design Validation

General process flow for validating a composite part can meet a desired performance criteria



What Can Influence Composite Performance?

- Fiber directionality
- Weave type
- Epoxy saturation + uniformity
- Presence of voids
- Cure temperature
- Fatigue behavior + microfractures
- UV exposure
- Resin age
- Is your geometry as expected? (radii)
- When was your latest sacrifice at the altar of the composite gods?

So…. why isn't FEA enough to predict how our composites will act?

Short answer: Composite properties are **incredibly process dependent**. How do you know the material properties you're using for FEA line up with reality of your process, given the list on the last page?

What can we do in buggy?

- Coupon testing for FEA material properties
- Destructive testing on old buggies!
- Non-destructive testing*
- Use known construction methods
- When in doubt, overdesign

*keep fatigue in mind, don’t test too frequently or too close to failure

What can we do in buggy?

Coupon testing

Make a coupon or sample part, test for material properties (i.e. with an instron). *It is easier to get better layup quality (e.g. resin saturation uniformity) on a part with simple geometry, so this may not be representative of your shell layup quality.*

How do you know that your coupon properties match the "real" part? **What can be controlled or inspected for in your process?** Fiber direction? Epoxy saturation? Geometry?

Also think about boundary conditions in your FEA– but that's a whole different lecture.

This will improve your FEA but is still **not enough to predict actual part performance** without further physical testing on parts with representative geometry and process.

What can we do in buggy?

Use known construction methods

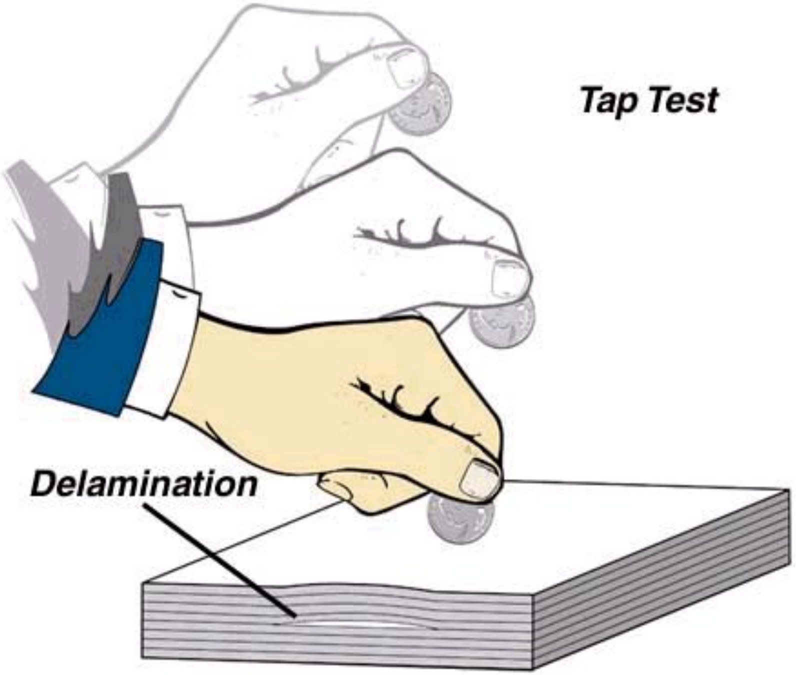
You can validate a specific construction method by destructive testing an old buggy, or making sample parts to destructive test.

An example of this is Lewis's work with validating a buggy hard point construction method through the BAA endowment. This work will be posted on the BAA website in the future!

When using a "known construction method" it is *very* important that your layup quality matches or exceeds that of the previous (tested) parts. **It is important to have detailed documentation of process and process controls (e.g. weighing the part post-cure to check epoxy saturation).**

5 - Common Composites Issues in Buggy

What is delamination?



Listen for:

- Crinkling
- Popping
- Lara telling you you have delamination

Image: https://www.eaa.org/eaa/aircraft-building/builderresources/while-youre-building/building-articles/composite/repairing-composite-surfaces

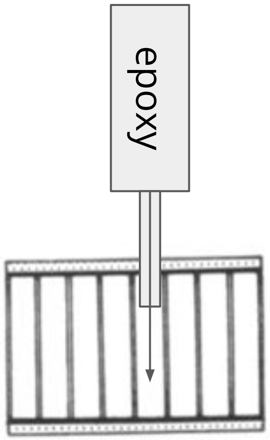
Critical areas on your buggy:

1. Driver hard points
2. Steering and axle hard points
3. Nose of your buggy (front ~6in)

No delam is good delam. **Once delam starts in a small area, it can/will get bigger**

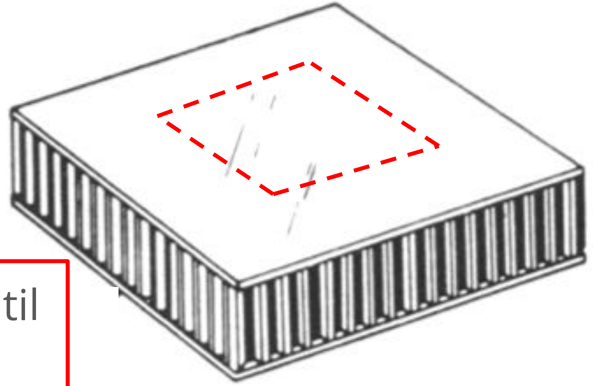
Also check: pushbar attachment, windshield attachments, hatch attachments

Composite repairs



Method 1: Resin injection

Method 2: Cut and patch with new reinforcement strips



Delam repairs are at best a stop-gap solution until you can get a new buggy constructed.

Images: aerospaceengineeringblog.com/sandwich-panel/

Further Resources

Carbon Fiber Fabrics

Description of weave types - https://www.elevatedmaterials.com/carbon-fiber-weaves-what-they-are-and-why-to-use-them/

Info on spread tows: https://www.researchgate.net/figure/Regular-tow-weave-vs-spread-tow-weave-thickness_fig1_277852995

https://www.compositesworld.com/articles/the-spread-of-spread-tow

Biaxial NCFs:

https://www.multiaxialfabrics.com/carbon-fiber-biaxial-fabrics/?lang=en

Layup Processes

I know I didn't walk through any one process step-by-step. Here are some great resources for that info:

The "How To Build A Buggy" book on the BAA website:

- https://cmubuggy.org/reference/how-to-build-a-buggy/

Easy Composites videos:

- Wet Layup - https://www.youtube.com/watch?v=cj26c3V54SQ
- Resin Infusion - https://www.youtube.com/watch?v=pWRVVLJX8eE
- Prepreg - https://www.youtube.com/watch?v=HfrFaKDsJxc
- Forged CF Compression Molding - https://www.youtube.com/watch?v=25PmqM24HEk