Ideal Automotive Applications for Curved Pultruded Sections: Material Selection, Design, Testing, and Production

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Vectorply Corporation, Scott Bader, & Shape Corporation

VECTORPLY CORPORATION OVERVIEW

- Headquartered in Phenix City, Alabama
- Founded 1992
- Privately Owned
- 200+ Employees
- NCS Reinforcement Fabric Supplier
- Material Solution Provider
- Applications Served:
  - Automotive
  - Industrial
  - Marine
  - Aerospace/Defense

Established in 1921, Scott Bader are an innovative global manufacturer of adhesives, resins, gelcoats and functional polymers with a unique ownership structure.

How we are different:

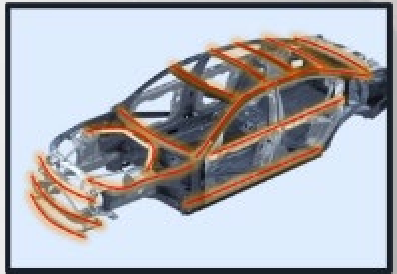
- An independent, creative and reliable
international business. ‘Owned in common’
by all who work in it. Our independence is
ensured by our ownership with all the company shares being held in charitable trust
- Everyone can make a difference. All colleagues can influence the direction the company takes
- All colleagues are engaged overall governance of Scott
- We cannot be bought out, allowing
us to maintain long-term relationships
with customers and supplie
- Integrity and honesty

SHAPE CORPORATION OVERVIEW

- Headquartered in Grand Haven, Michigan
- Founded 1974
- Privately Owned
- 3,000+ Associates
- Tier 1 Automotive Supplier
- $800M Company

Shape began its composites journey in 2014

- Partnered with Thomas Technik on Radius Pultrusion
- ACE Finalist - CAMX 2017 for “highly engineered hollow profiles”
- Supplying GM Carbon Bumper



Current Status:

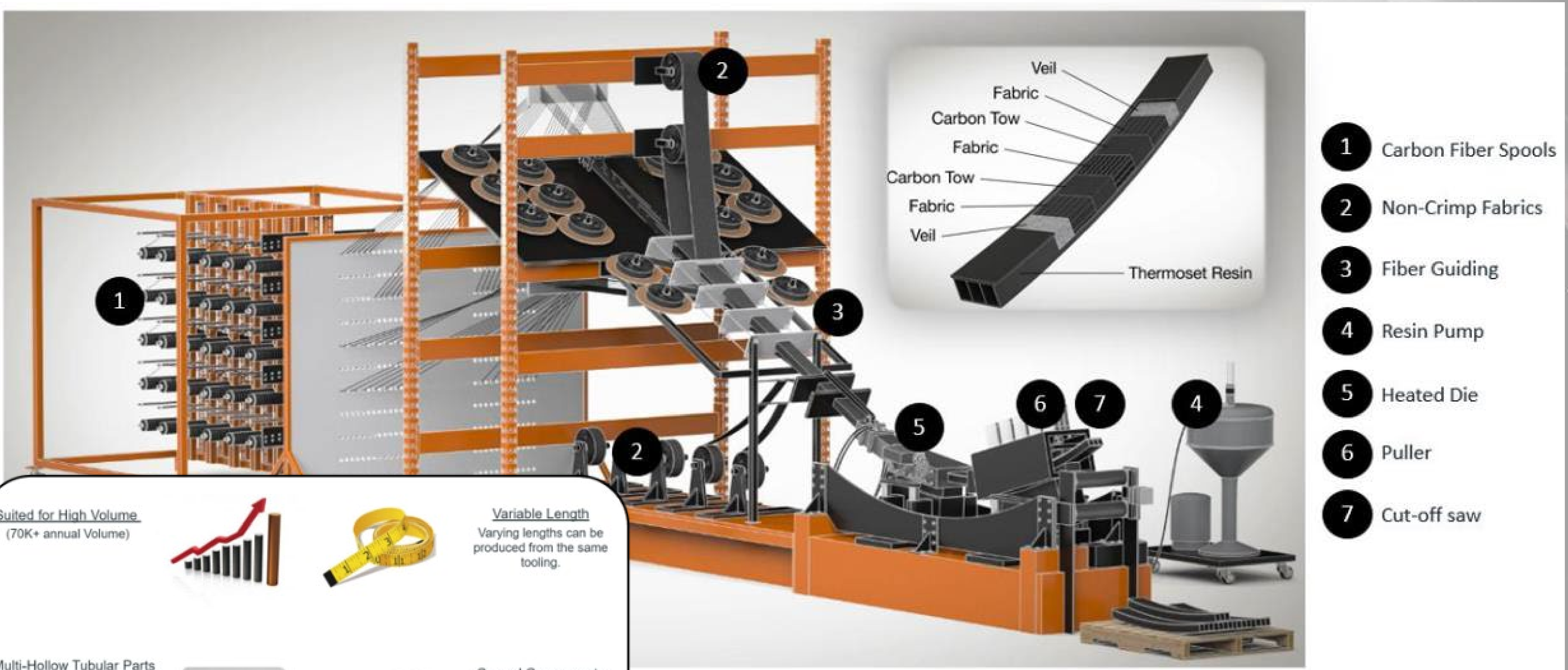
- Production of Corvette carbon fiber rear bumper
  - Joining of composite-metal systems established
- Hybrid designs to reduce cost v. all-carbon components
- Focused on OEM product pull & alignment

Curved Pultrusion

Glass/Carbon Hybrid Composite

PROCESS OVERVIEW

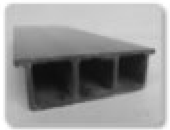
RADIAL PULTRUSION - OVERVIEW



Suited for High Volume
(70K+ annual Volume)

Variable Length
Varying lengths can be produced from the same tooling.

Multi-Hollow Tubular Parts
Offers stronger profile, leading to increased torsional stiffness and performance. Reduced mass and cost can be achieved with a tubular closed section design.



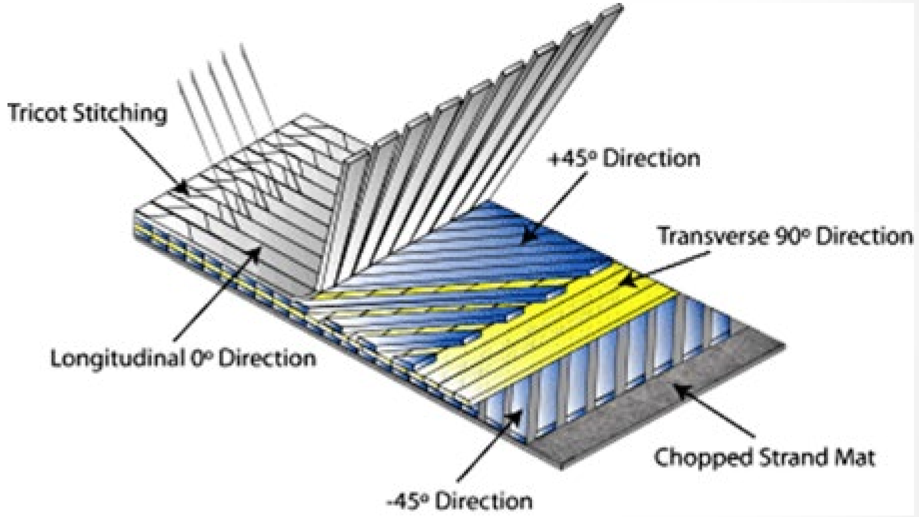
Curved Components
Adding curvature increases flexibility in the design of end products and unlocks new applications for composites

Full Video: https://www.shapecorp.com/manufacturing/composites/

MATERIALS

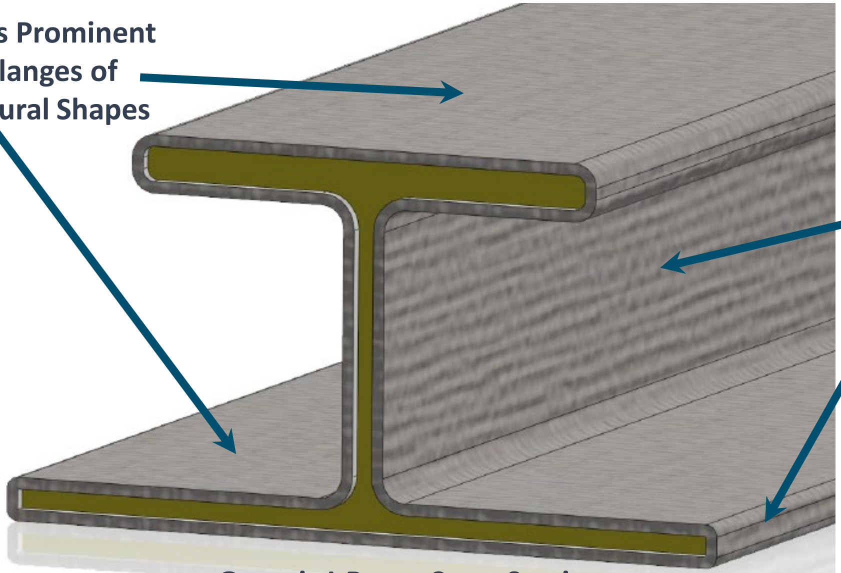
TAILORED REINFORCEMENT – NON-CRIMP FABRICS

- NCF's: Reinforcement fiber layers/plies are assembled and stitched into fabric using warp knitting technology
- The fibers are kept straight and in distinct plies, providing higher levels of mechanical performance compared to random short fiber mat or woven fabrics
- Fiber plies are placed in specific angle orientations as needed to optimize performance and minimize cost
- Standard constructions include:
  - Unidirectional [0°] & [90°]
  - Biaxial: [0°/90°], [+45°/-45°], [+60°/-60°]
  - Triaxial: [0°/+45°/-45°], [+45°/90°/-45°]
  - Quadraxial: [0°/+45°/90°/-45°]

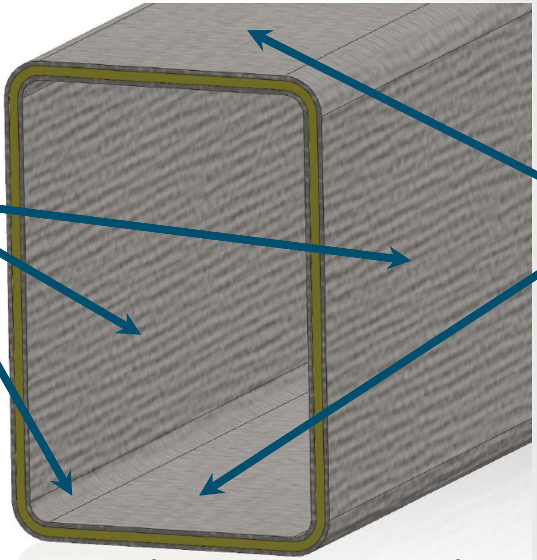


TAILORED REINFORCEMENT – NON-CRIMP FABRICS

- Multiaxial NCF's provide efficient continuous fiber reinforcement to pultruded components
  - 0° plies of [0°/90°] biaxials, [0°/+45°/-45°] warp triaxials, & [0°/+45°/90°/-45°] quadraxials
    - Provide bending & in-plane tensile/compressive stiffness and strength along the pultruded beam profile
    - Can replace layers of single end roving
      - Smaller fabric creels replace large roving creels, saving space and set up time
      - Fabric allows for more efficient tracking through dies
  - Bias angle plies (i.e. [+45°/-45°], [+60°/-60°]) of biaxials, triaxials, & quadraxials
    - Provide shear & torsional stiffness and strength along the pultruded beam profile
    - Not possible to efficiently orient continuous fibers at bias angles with single end roving unless they are in a fabric form
    - Quasi-isotropy allows for other functionality such as increased fastener bearing strength & radius/corner strengthening
    - 90° plies provide dry fabric stability (consistent fabric width), increases transverse stiffness/strength & shear web buckling resistance



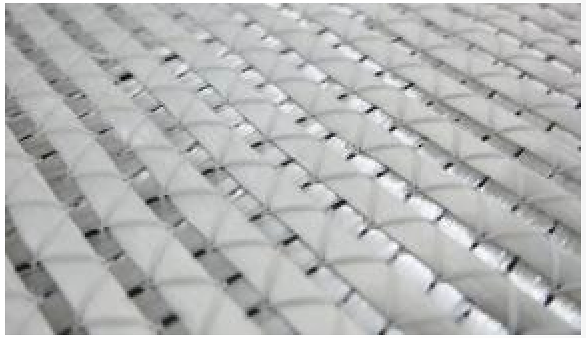
Generic I-Beam Cross Section



Generic Box-Beam Cross Section

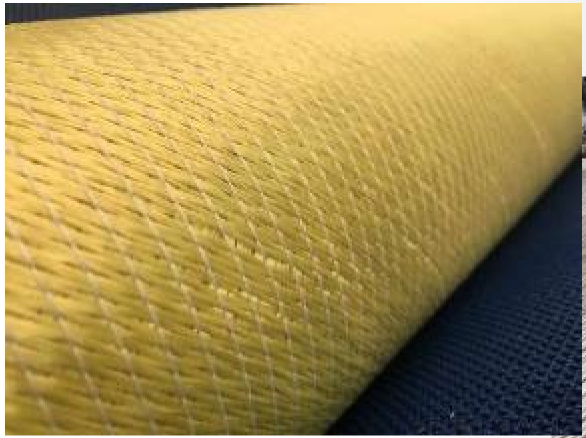
TAILORED REINFORCEMENT – NON-CRIMP FABRICS

- Reinforcement fibers typically used:
  - **Glass Fiber** – Grades E, ECR, H, R, & S/S2
    - For moderate modulus/specific modulus, and high strength applications
    - Insulative & corrosion resistant
    - Most cost effective
  - **Carbon Fiber** – Standard, intermediate, & high modulus
    - For high specific modulus & strength applications
    - High fatigue resistance
    - Thermally and electrically conductive
    - Galvanically corrosive with metals
  - **Polymer Fiber** - High modulus, composite grade (non-ballistic)
    - Includes para-aramid (Kevlar®& Twaron®), HMPP (Innegra™), & others
    - Can provide high specific strength, impact/dynamic loading resistance
    - Very useful in hybridized reinforcements with glass and/or carbon fibers



E-glass [0°/90°]

Std Modulus Carbon Fiber Tow

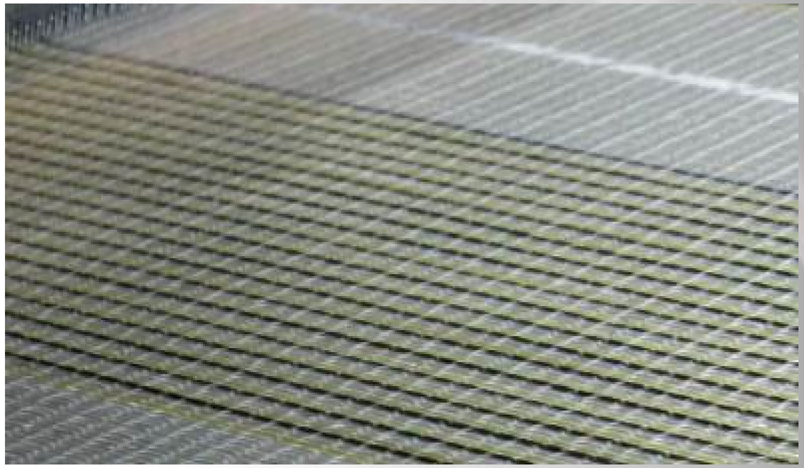


Para-Aramid [+45°/-45°]

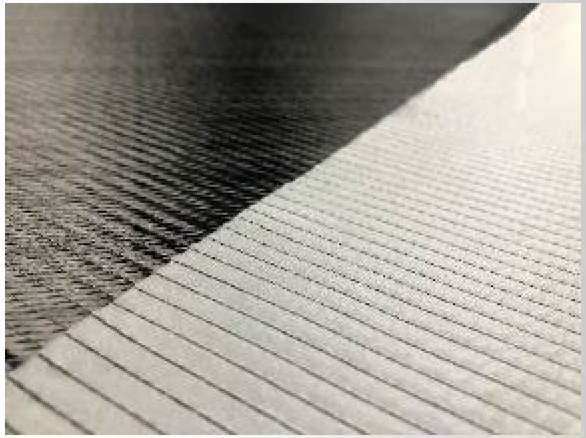
HMPP (Innegra™) Fiber

TAILORED REINFORCEMENT – NON-CRIMP FABRICS

- Fabric options
  - Vary individual ply Fiber Areal Weight (FAW)
  - Ply stacking sequence can be altered
  - Hybridize within a ply (intraply) or within the fabric (interply)
  - Can attach “substrates” to one/both sides
    - Veils (glass or polymer fiber based) or mats for low surface profile or higher resin content
    - Other fabrics or meshes to add other functionalities (thermal/electrical properties)
    - More efficient tracking through die compared to unattached veil/mat/fabric
    - Can provide dry fabric tape width stability during dry pull through the die



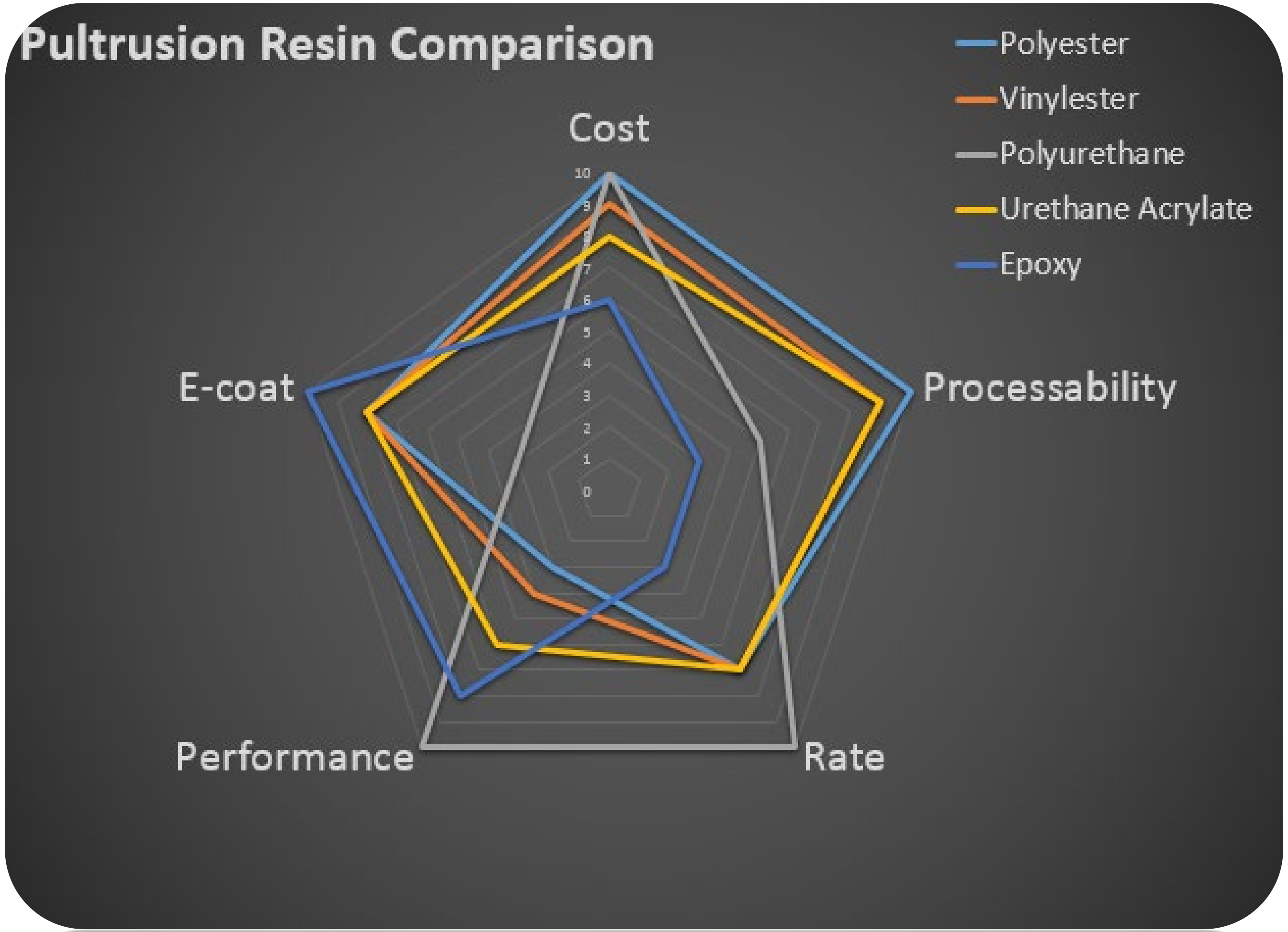
Intraply Hybrid: E-glass, Carbon, & Aramid



Interply Hybrid: Carbon & PPS Veil

Interply Hybrid: E-glass & Carbon

TAILORED MATERIALS – RESINS



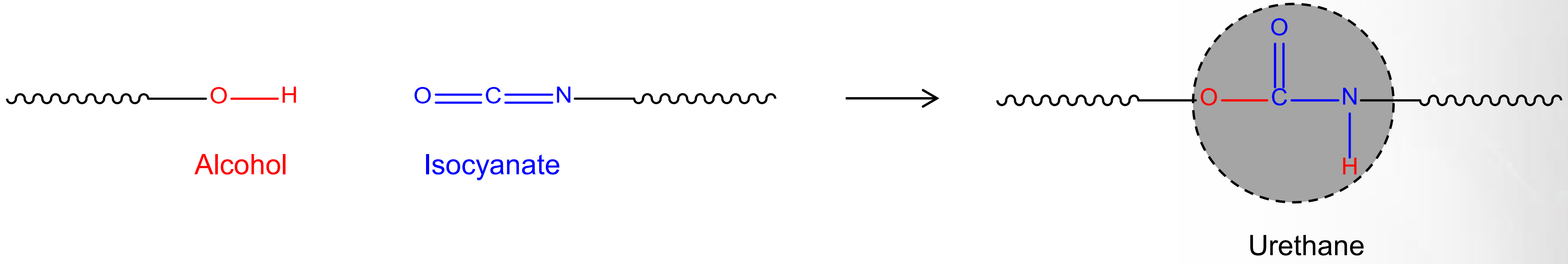
- Custom Formulations for Product Requirements
  - Thermoset Resins
    - Chemistry can be tailored for processing and performance

URETHANE ACRYLATES

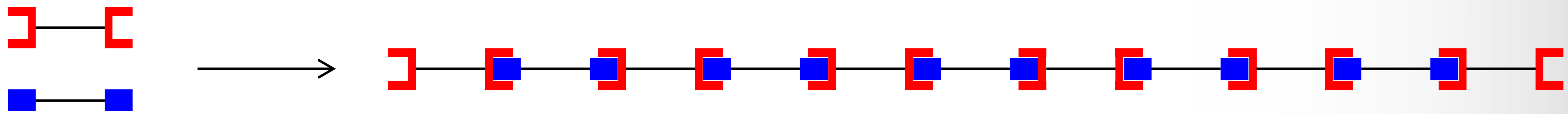
Need to define a few terms

What is a urethane?

"the reaction product of an alcohol with an isocyanate"



Polyurethanes therefore are formed from the reaction of **di**ols and **di**socyanates and reach high molecular weights

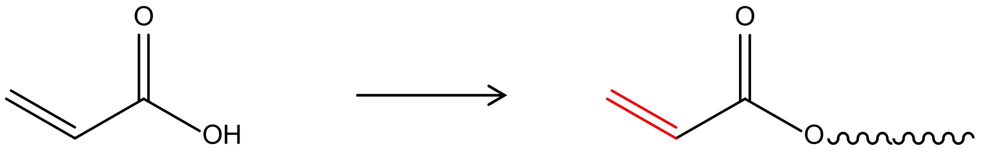


URETHANE ACRYLATES

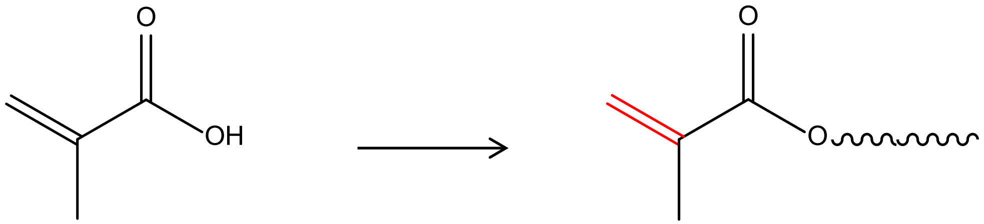
Need to define a few terms

What is an acrylate?

"an ester derivative of acrylic acid"



Acrylic acid | Acrylate



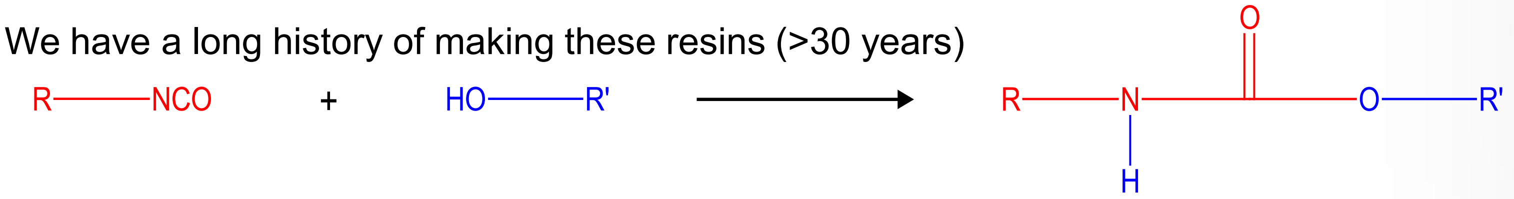
Methacrylic acid | Methacrylate

The double bond is the source of the unsaturation in urethane… It is where your initiators react to form the necessary chains… Meaning if your resin did NOT cure, there was no reaction with these bonds.

URETHANE (METH)ACRYLATE INTRODUCTION

<u>Crestapol</u> is the tradename for our range of urethane (meth)acrylate, high performance resins.

We have a long history of making these resins (>30 years)



Traditionally have been used to add value to our adhesives (toughness, elongation, stiffness etc) and therefore manufactured and consumed internally.

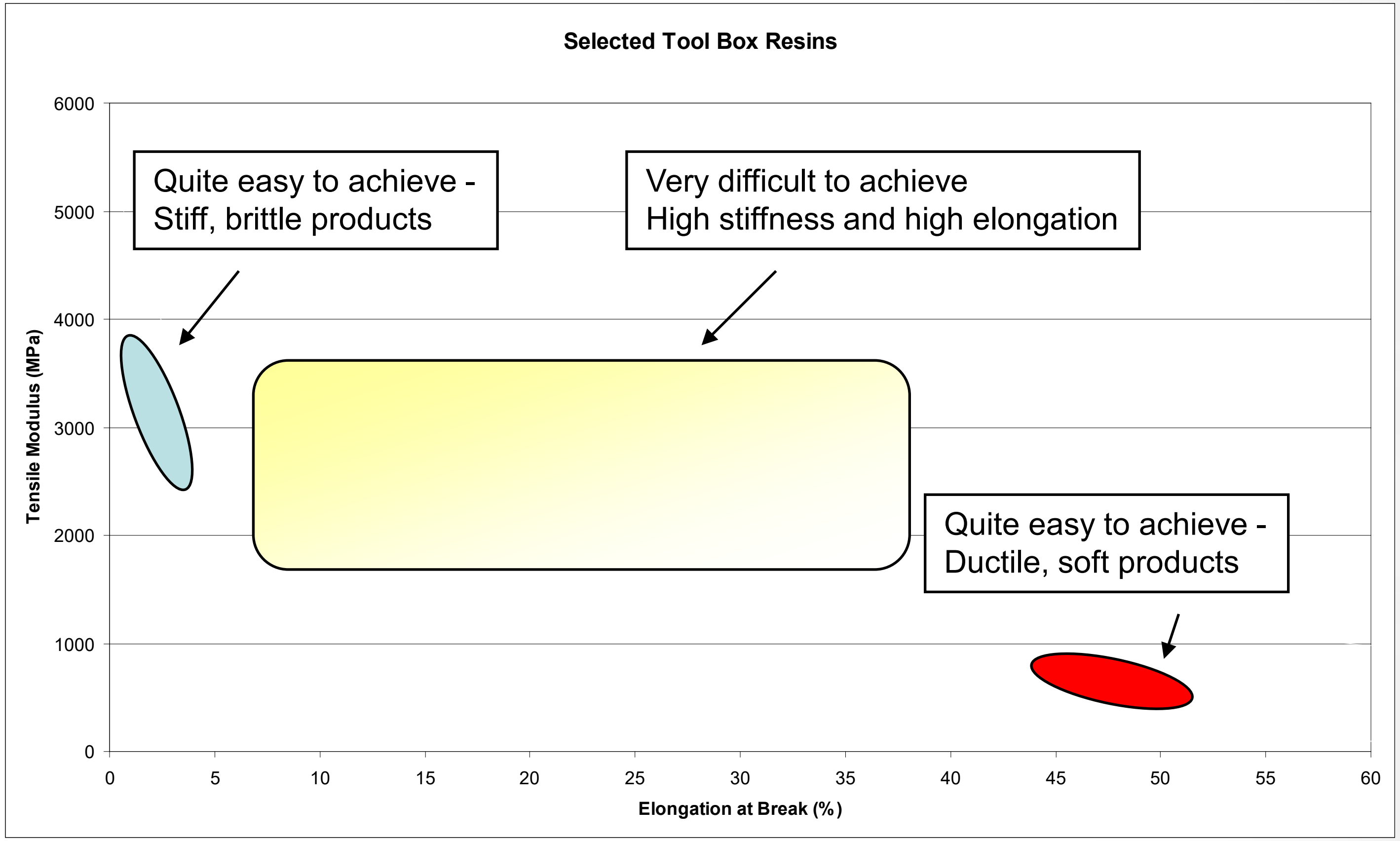
More recently they have found use in certain composite applications where people have demanded better performance than from UPRs (open mould, pultrusion, infusion, fire retardancy, certain gelcoats etc)

Careful control of R and R' can give rise to a wide array of very interesting products with diverse properties

We believe we can achieve much more with the technology however

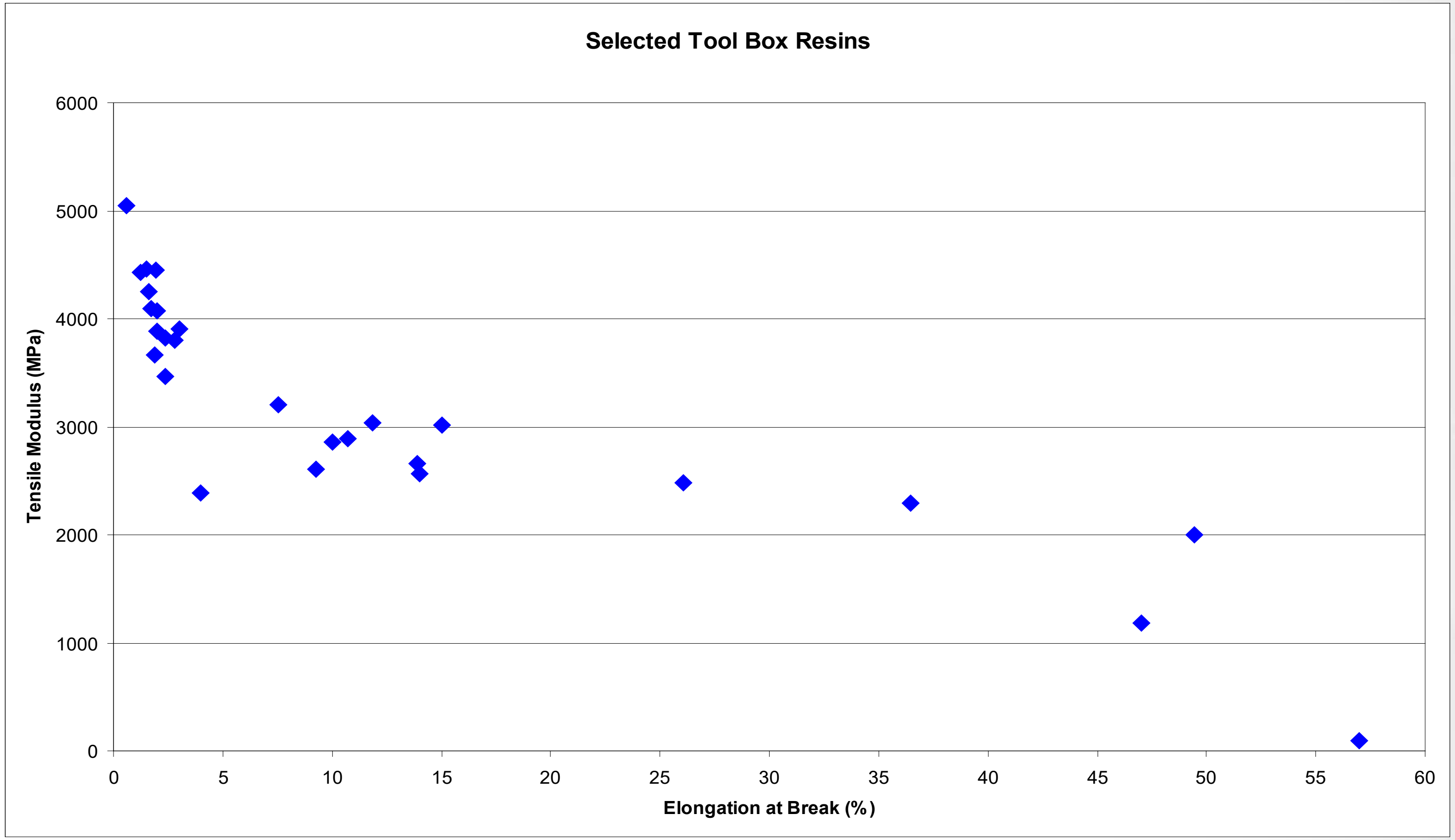
URETHANE (METH)ACRYLATE INTRODUCTION

From our experience on polyesters we know it is very easy to make a very stiff material at the loss of elongation. And *vice versa* we can make very high elongation materials with fairly poor mechanical stiffness.



URETHANE (METH)ACRYLATE INTRODUCTION

We have now, identified a number of resins that are appearing in the “very difficult to achieve” region which is very exciting.



URETHANE (METH)ACRYLATE INTRODUCTION

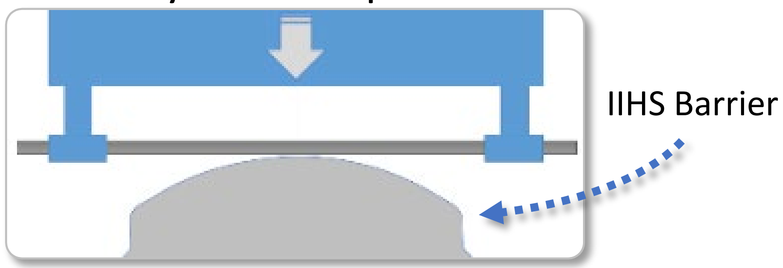
Some of the interesting properties we have been able to achieve

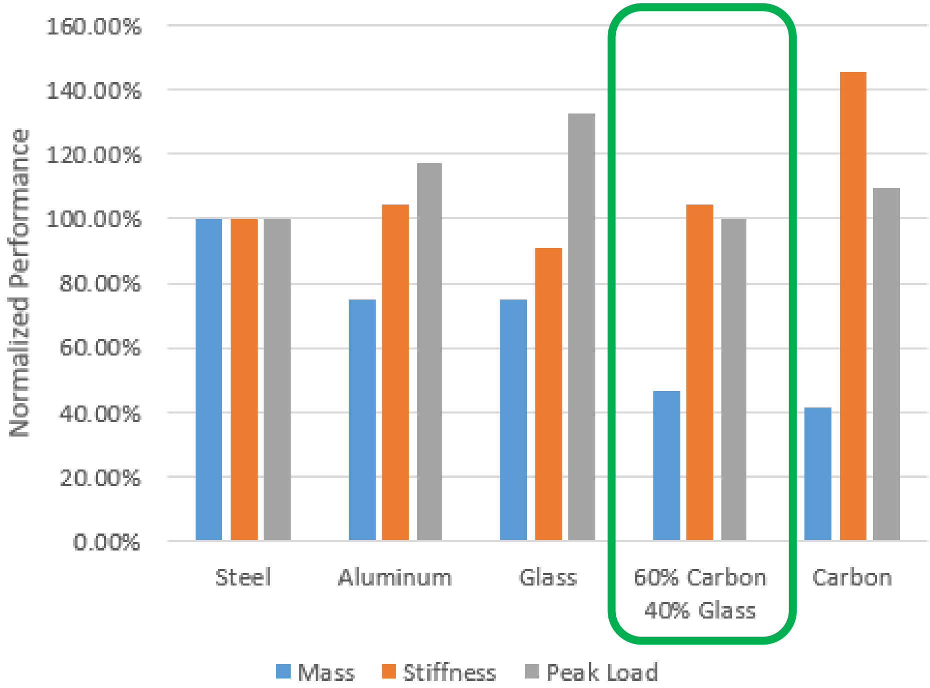
- Crestapol 1255 – Resin with 33-50% increased line speed vs Vinyl Ester resins
- Uncommercialized resin that can achieve Tg's of 300 C, also extremely fast curing speed
- Increased toughness additives for tradional resin
- For Fire Applications, these UA's offer greatly reduced smoke and the ability to pass E 84 Class 1 for smoke and fire when ATH is added.
- We have versions of these resins that offer significantly improved UV as well.

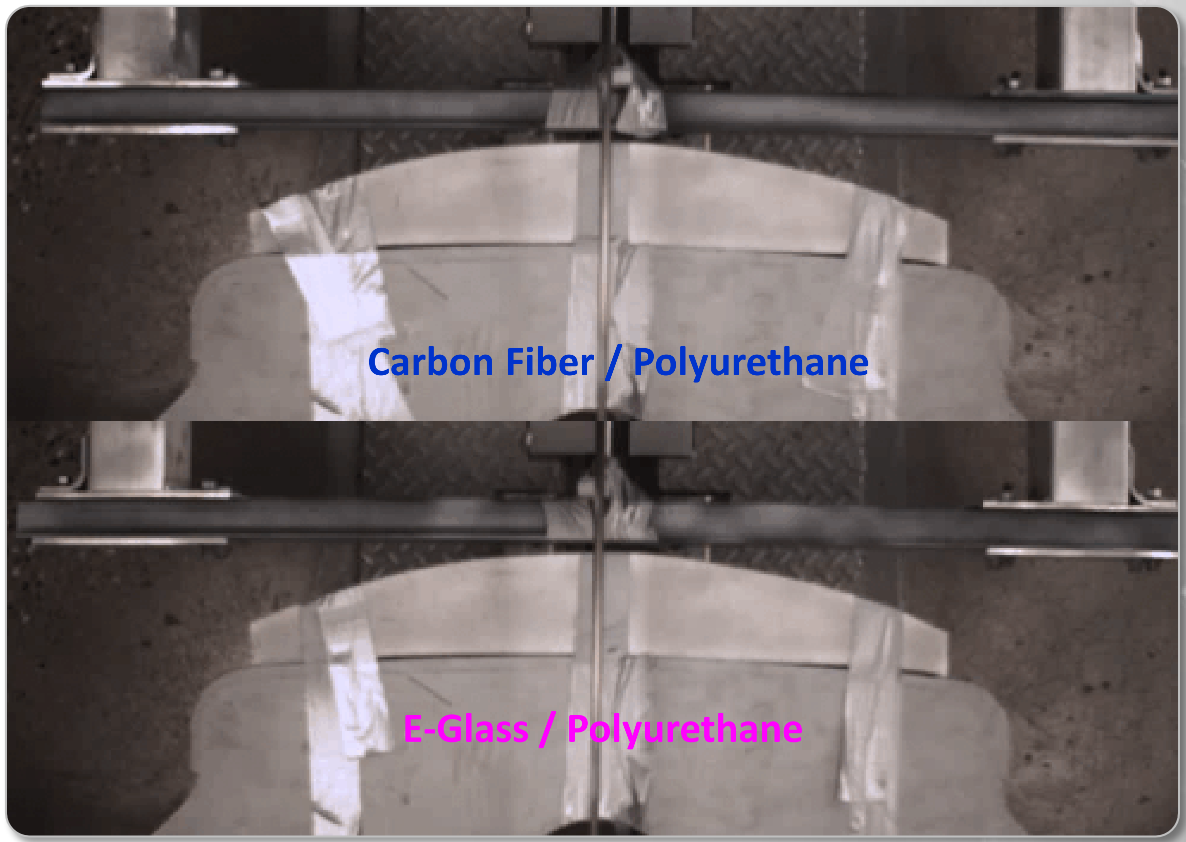
CHALLENGES

MATERIALS & COST

Dynamic Impact







JOINING & INTEGRATION

PROBLEM

Aluminum-to-Carbon-Fiber interface is VERY galvanically reactive

WITHOUT countermeasures

WITH countermeasures

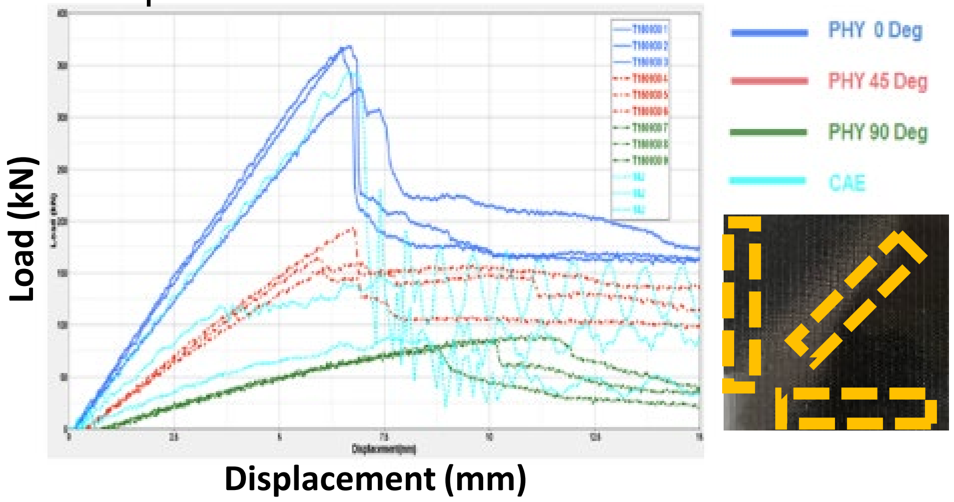
Engineers should be aware of potential galvanic corrosion when designing lightweight multi-material solutions

SOLUTIONS

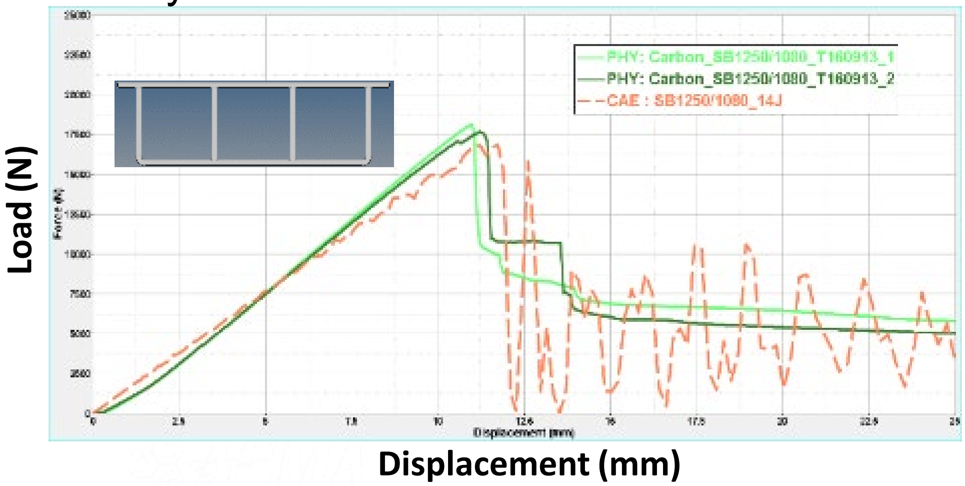
- Physically separate carbon fiber from metallic materials
    - Use hybrid reinforcement
        - Glass or polymer fiber plies in direct contact with metal
    - Use non-conductive adhesive
    - Use non-conductive sleeves (for metallic fasteners in carbon fiber laminates)
- Use cathodic (more noble) metals
    - Titanium
    - Select stainless steels (ex. 316)

INITIAL DESIGN PROPERTIES - TESTING

Coupon Validation



Physical Correlation



1. Create a plaque with the desired fiber / resin combination
2. Test dog-bone coupons in 5 conditions from plaque
3. Populate CAE Material Card with experimental data
4. Run physical and CAE 3 point bend test on plaques

   Continue if CAE matches physical test – otherwise update the material card

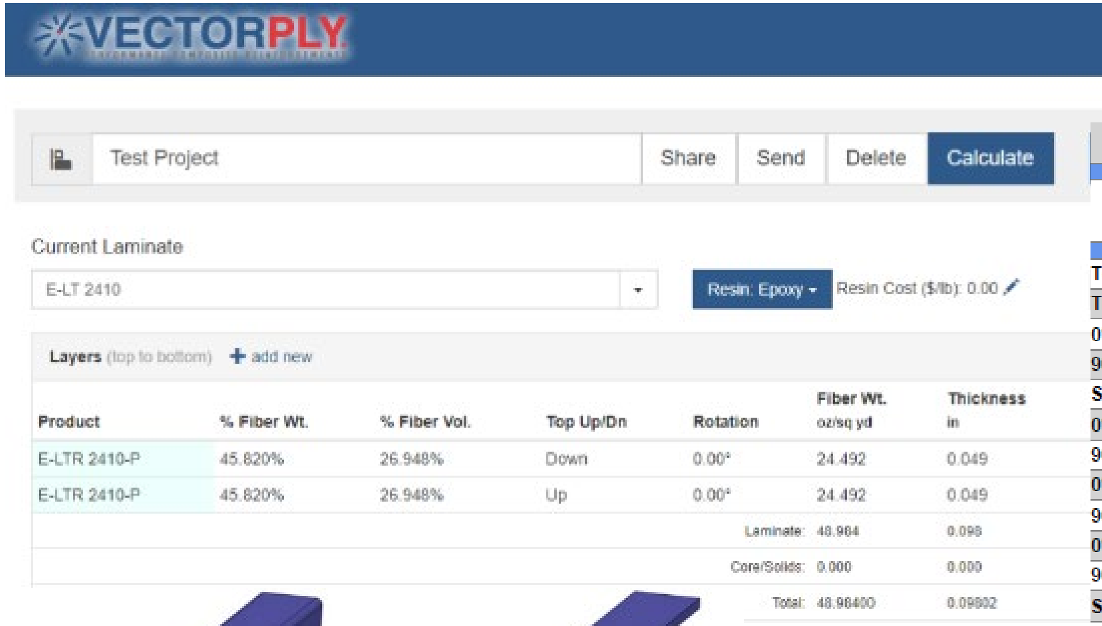
5. Run physical and CAE full part test (impact, crush etc.)

   Continue if CAE matches physical test – otherwise update the material card

6. Design optimization

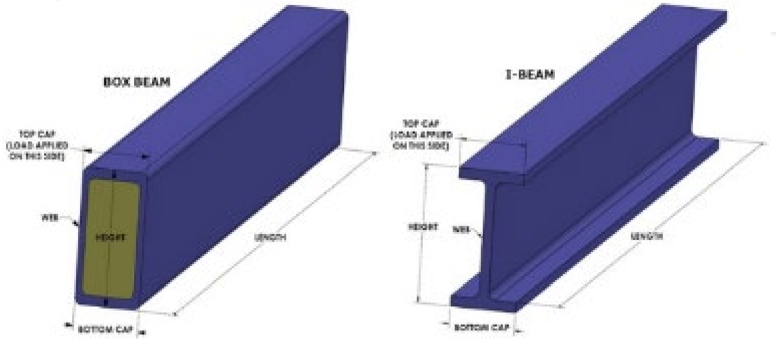
PREDICTABILITY

- Preliminary laminate properties are generated using VectorLam™ design tool
  - Classical Laminate Theory (CLT) based, useful for material selection & preliminary structural designs
  - Candidate laminate schedules are quickly analyzed to determine strength, stiffness, mass/weight, & cost
  - Can vary fiber volume or weight fractions, ply orientations & stacking sequences to determine effects



VECTORLAM
LAMINATE ANALYSIS SOFTWARE VERSION 3.0

		E-LT 2410	Woven Laminate	3408
Layer	1	E-LTR 2410-P	24oz Woven Roving	E-TLXM 3408
	2	E-LTR 2410-P	24oz Woven Roving	
Total Wt.	lb/ft²	0.74	0.70	0.60
Thickness	in	0.098	0.082	0.071
0° Modulus, Ex	Msi	1.953	2.239	2.135
90° Modulus, Ey	Msi	1.890	2.031	1.431
Shear Modulus, Gxy	Msi	0.272	0.423	0.773
0° Flex. Stiffness	lb-in²/in	81.21	98.84	73.92
90° Flex. Stiffness	lb-in²/in	184.12	91.83	36.07
0° Ten. Ult. Stress	ksi	36.965	34.930	31.248
90° Ten. Ult. Stress	ksi	35.778	31.695	13.882
0° Comp. Ult. Stress	ksi	36.965	31.018	40.909
90° Comp. Ult Stress	ksi	35.778	28.145	13.882
Shear Ult. Stress	ksi	5.434	8.460	14.948
Vf	%	26.9	32.1	31.4
Wf	%	45.8	50.0	49.2
Poisson Ratio, PRxy		0.14	0.17	0.37
0° Ult. B. Moment	in lb/in	32	55	31
90° Ult. B. Moment	in lb/in	73	52	24



FIRE, SMOKE, & TOXICITY

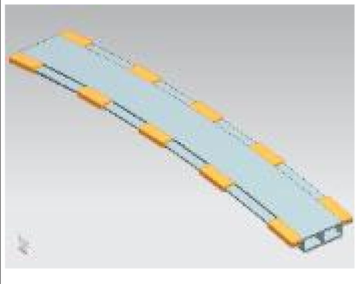
- Polymer resins and fibers can provide fuel for fire/smoke/toxicity averse applications
- Options for suppressing FST
  - Halogenated (brominated, chlorinated) resins reduce oxygen content during fires, but can still be toxic
  - Additives: Alumina Trihydrate (ATH) evolves water at high temperatures
  - Typical styrenated resins produce black smoke, while MMA based resins are more clear/white & work well with ATH
  - Intumescents: Use as a paint, resin additive, or in dry fabric/roll good form

Intumescent Fabric Combined with CFM

APPLICATIONS

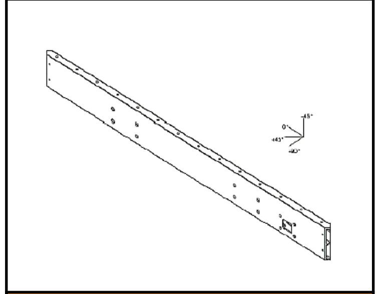
AUTOMOTIVE APPLICATIONS

Structural Components

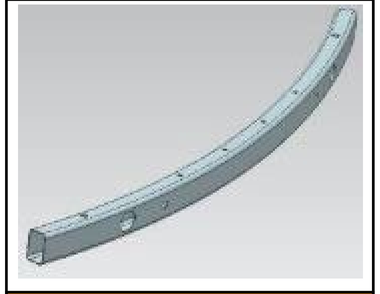


Roof Bow

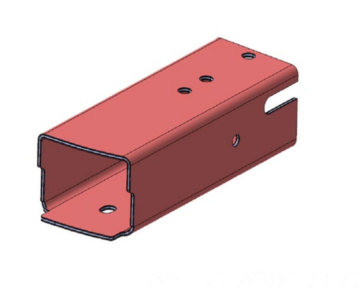
Rocker



Battery Tray Frames



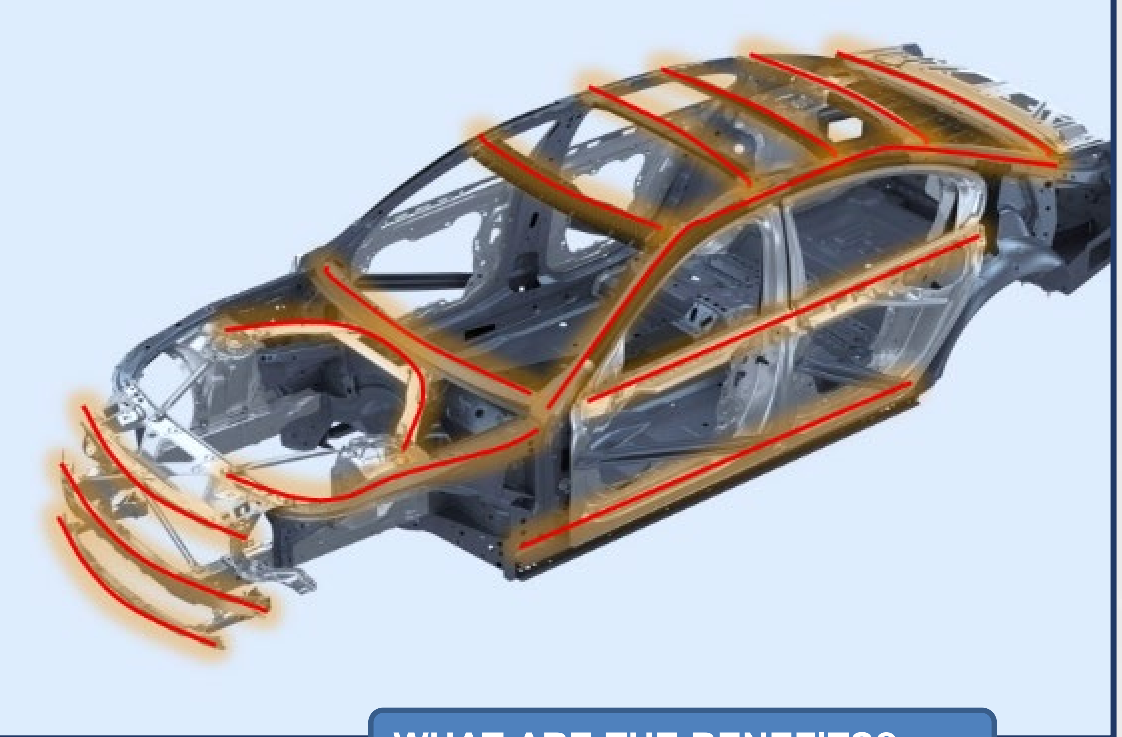
Lower Bumper

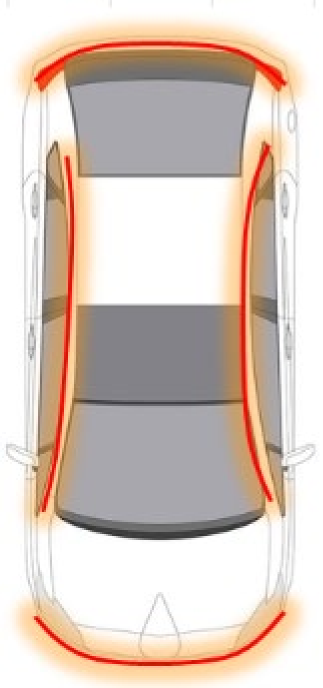


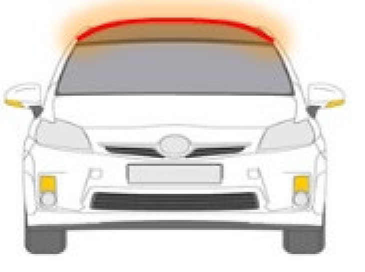
Crush Cans

Bumper

WHERE IS THERE STRUCTURE?







WHAT ARE THE BENEFITS?

- 20-60% mass savings
- Est. Cost Premium $2-20 per kg saved
- Tailored for load cases or CLTE

*Part consolidation may reduce further

THANK YOU!

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