VECTORPLY®
PERFORMANCE COMPOSITE REINFORCEMENTS

NCF REINFORCEMENTS FOR PULTRUSION APPLICATIONS: KEY ATTRIBUTES FOR SUCCESSFUL PARTS

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VECTORPLY CORPORATION

ABOUT US

Vectorply specializes in the development, production and sale of multi-axial, non-crimped, stitched reinforcement fabrics (also called NCF). The fabrics are used in combination with various resin systems to create composite products that can out-perform traditional materials. The company provides fabric to several industries throughout the Americas.

VECTORPLY FACILITIES

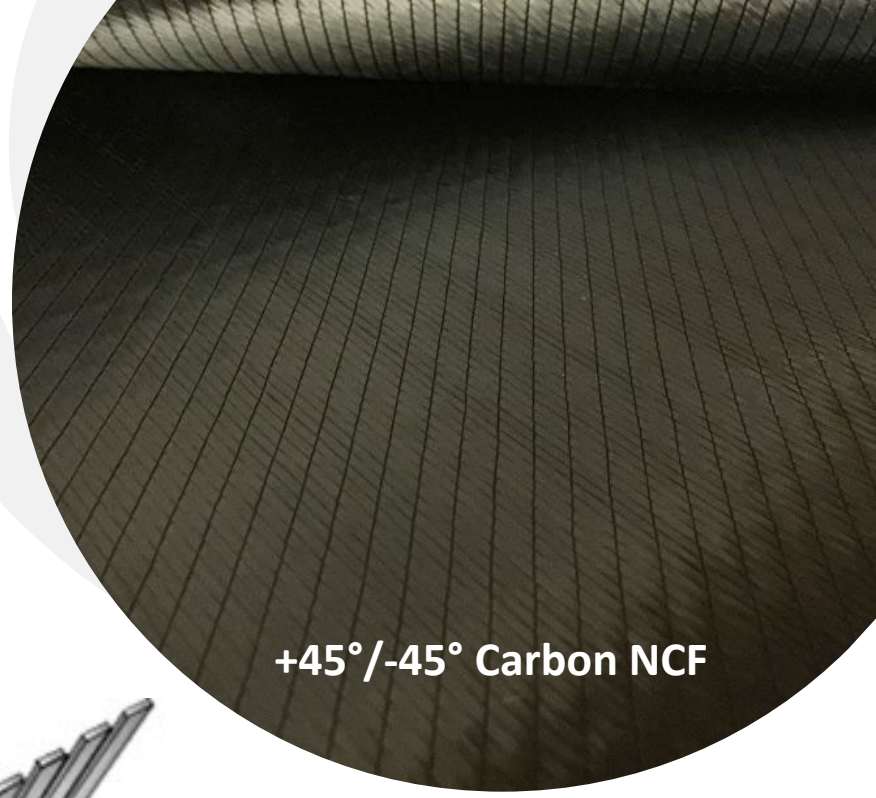
- **Located in Phenix City, AL Vectorply is roughly 105 miles Southwest of Atlanta, GA and just across the boarder from Columbus, GA**
  - **30 miles from Auburn, Alabama**
  - **105 miles from Atlanta, Georgia**
  - **215 miles from Huntsville, Alabama**
  - **255 miles from Mobile, Alabama**

CURRENT FACILITIES

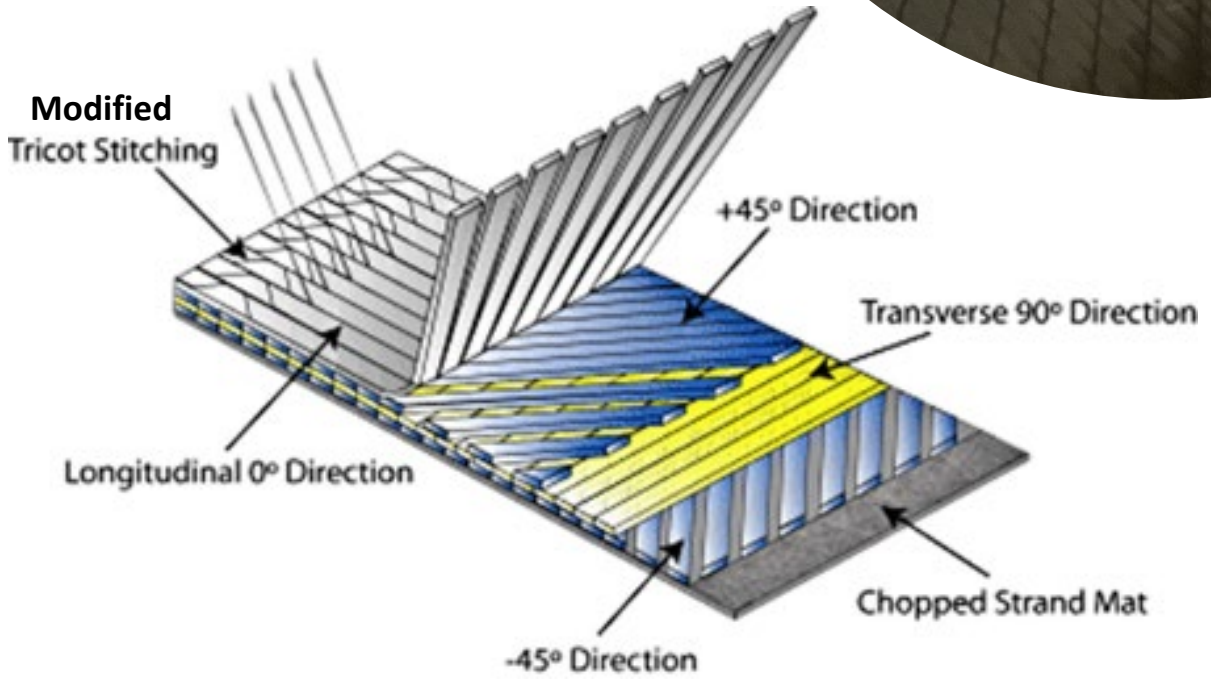
- 225,000 ft² of office and manufacturing space
- Advanced Composites Reinforcements Center featuring carbon manufacturing and test lab
- 31 machines (LIBA & Mayer)
- 190+ employees
- 3 shifts – 7 days per week
- Producing 350+ fabric styles
- Capacity in place to produce 80+ million lbs annually

NON-CRIMP FABRICS

- Non-Crimp Reinforcements, or **NCF**'s: Reinforcement fiber layers/plies 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°]



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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
  - **Natural Fiber (Flax)**
    - Good vibration damping, moderate mechanical properties, & low environmental impact
    - Can still have matrix-fiber interface and availability issues

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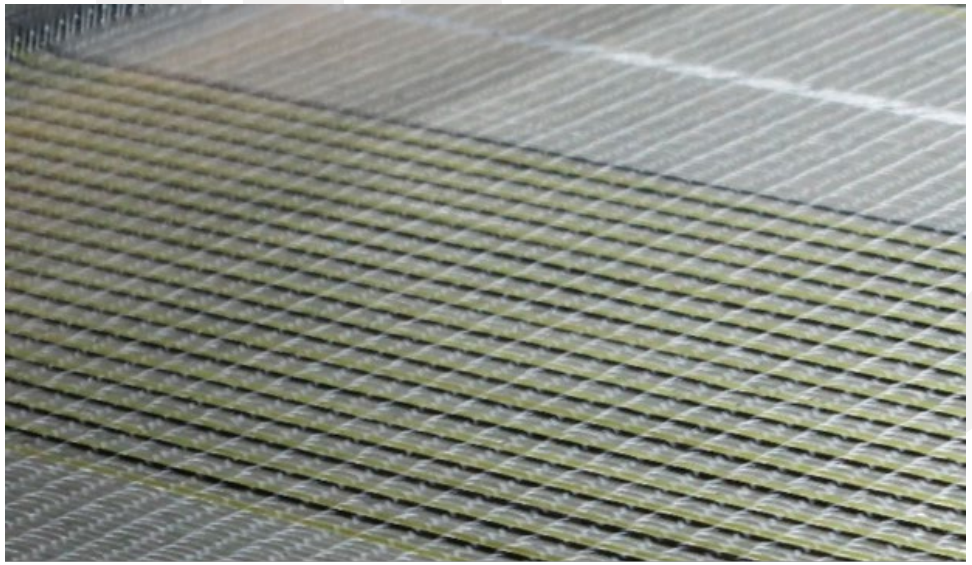
TAILORED REINFORCEMENT – NON-CRIMP FABRICS

- 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
      - Traditional CFM layers (0.75 -> 2oz/ft^2) are routinely added to NCF’s as substrates
    - Other fabrics or meshes to add other functionalities (thermal/electrical properties)
    - More efficient tracking through die compared to unattached veil/mat/fabric

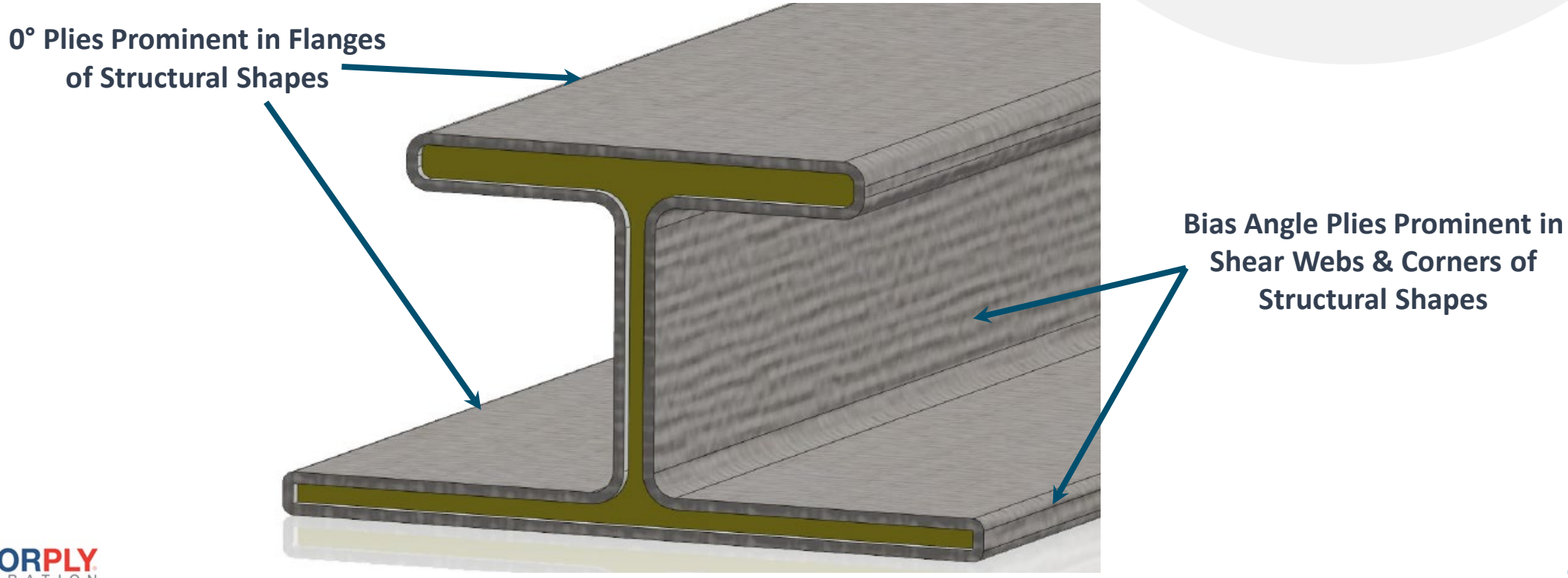


Intraply Hybrid: E-glass, Carbon, & Aramid

Interply Hybrid: E-glass & Carbon

TAILORED REINFORCEMENT – NON-CRIMP FABRICS

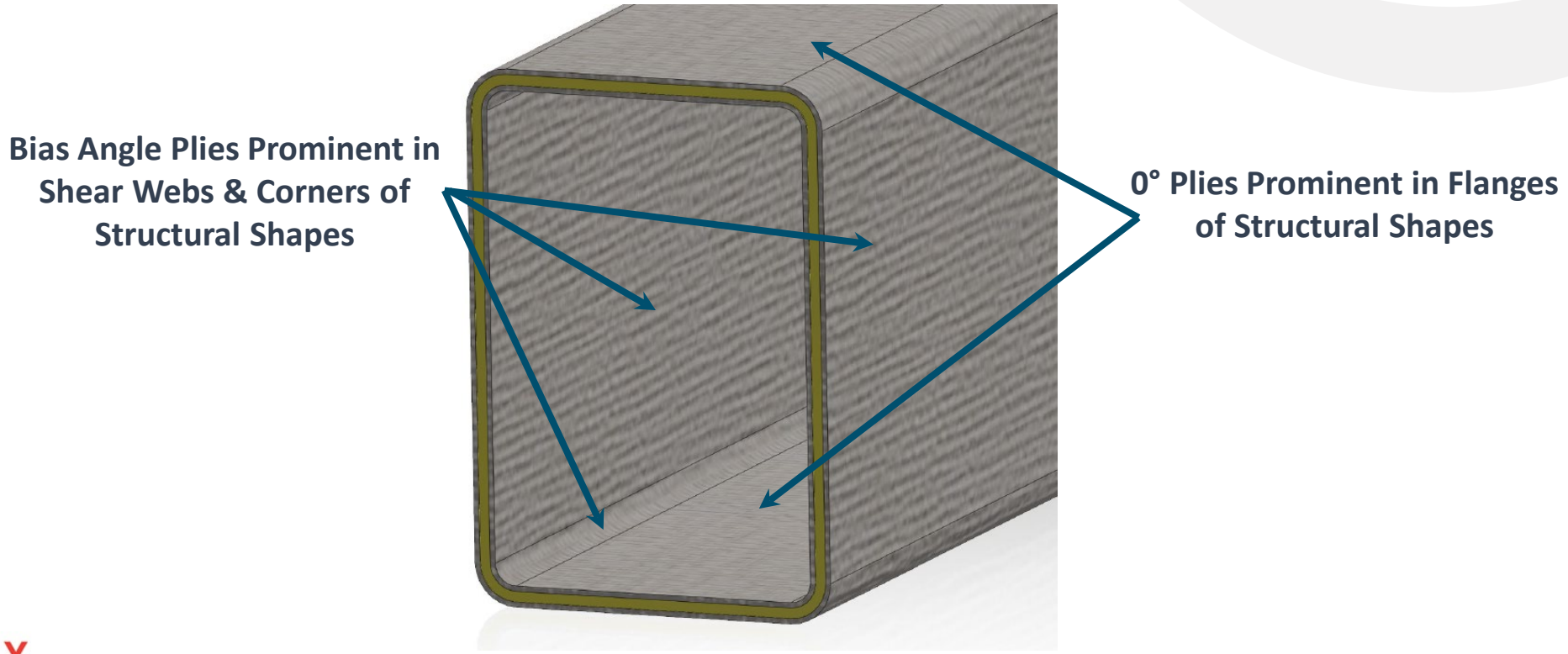
- Multiaxial NCF's provide efficient continuous fiber reinforcement to pultruded components
  - 0° plies of [0°/90°] biaxials, [0°/+45°/-45°] warp triaxials, & [0°/+45°/90°/-45°] quadraxials
    - Provide bending & in-plane tensile/compressive stiffness and strength along the pultruded beam profile
    - 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



Generic I-Beam Cross Section

TAILORED REINFORCEMENT – NON-CRIMP FABRICS

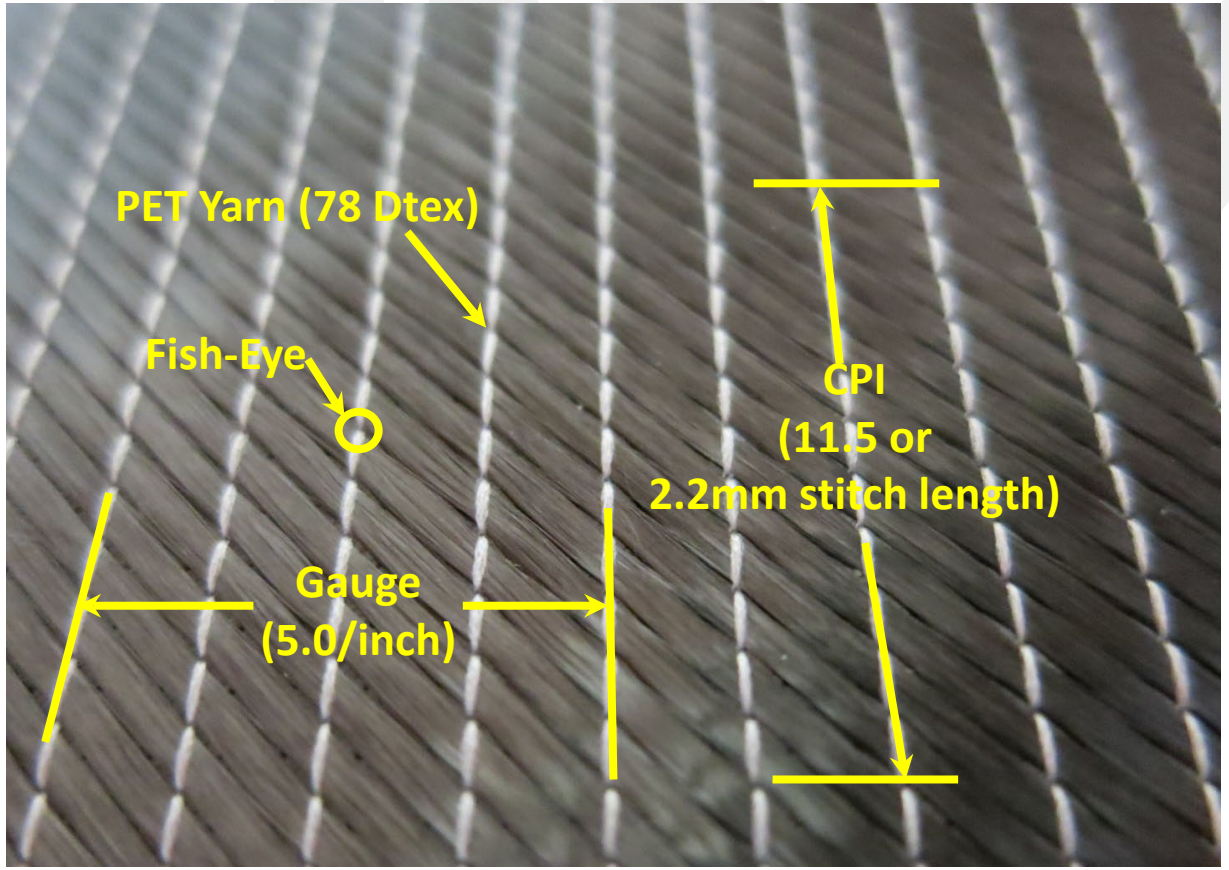
- Bias angle plies (i.e. [+45°/-45°], [+60°/-60°]) of biaxials, triaxials, & quadraxials
  - Provide shear & torsional stiffness and strength along the pultruded beam profile
  - Not possible to efficiently orient continuous fibers at bias angles with single end roving unless they are in a fabric form
  - 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 Box-Beam Cross Section

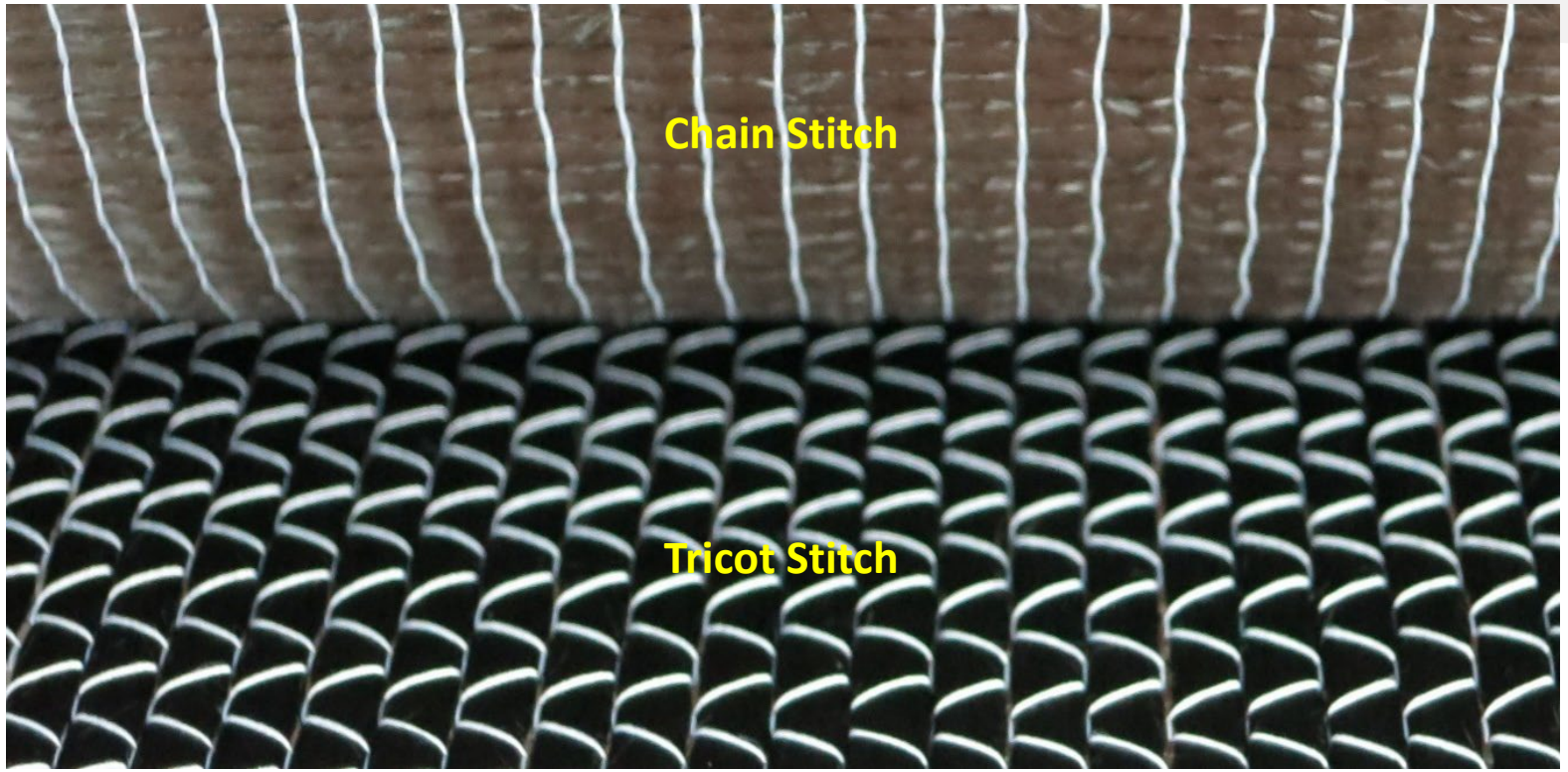
NCF PARAMETERS

- Effect on Processing & Composite Properties
  - Stitch Yarn
    - Yarn Size (Dtex or denier)
      - Lighter → Heavier: Increase in stability & fish-eye size; Lower microcrack resistance & fiber content
    - Gauge (Stitches per Unit Width)
      - Low →High: Increase in stability & stiffness, lower fiber content
    - CPI (Stitches per Unit Length)
      - Low → High: Increase in stability, stiffness, permeability, & cost
    - Run-in (Amount of Yarn per Unit Length)
      - Low → High: Reduction in tension, fish-eye size, & permeability; Increase in fiber content, microcrack resistance, & drapeability



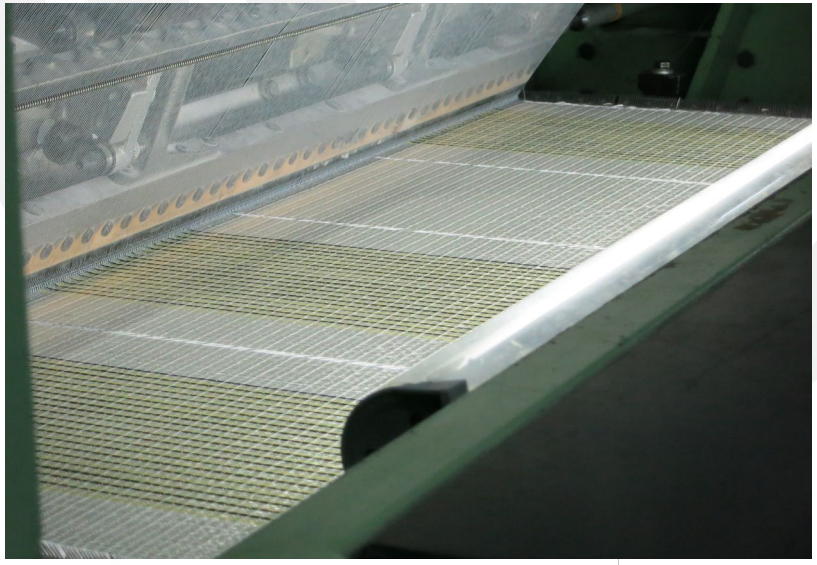
NCF PARAMETERS

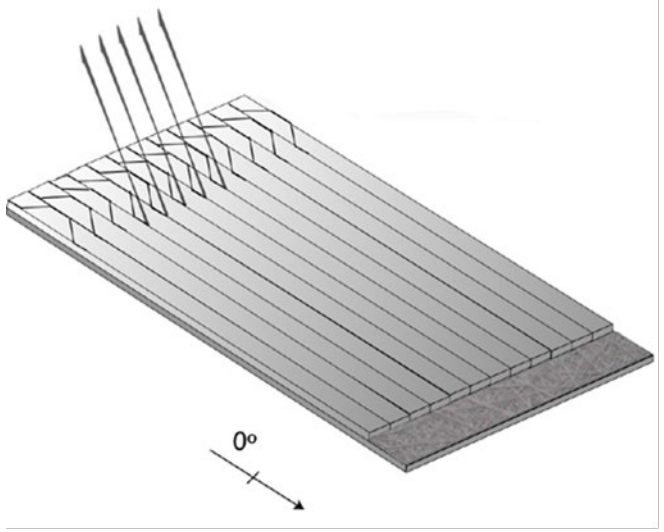
- Effect on Processing & Composite Properties
  - Stitch Pattern
    - Chain: Consistent fish-eye size, high columniation of tows (better compression properties) & drapeability
    - Tricot: High stabilization, inconsistent fish-eye size, in-plane fiber waviness (lower compression properties)
    - Modified Tricot: Combination of Chain and Tricot
      - Combination of properties



NCF CHALLENGES

- PET stitching can hamper performance in high temperature applications and resins
  - High temp stitch yarns are in development
- Warp unidirectional NCF's need a substrate
- Use of small tow (> 12K) carbon or yarn-style glass fibers can be difficult to process
- Added bias angle layers and fabric ply stacking can complicate extension-bending-twisting coupling effects
  - Can induce warping when using high-shrink resin systems with non-symmetric laminate schedules
- High dry fabric integrity/stiffness can cause issues with forming to tight radii compared to glass mats, polymer veils, and/or uni roving





0º Unidirectional w/Substrate

NCF VS CFM

CFM Laminate #1	
1	1oz Nexus Veil - pultruded
2	M8643 CFM 2oz - pultruded
3	113 yield Roving: 10 EPI - pultruded
4	M8643 CFM 2oz - pultruded
5	1oz Nexus Veil - pultruded

NCF Laminate #1	
1	1oz Nexus Veil - pultruded
2	E-TTX 2300 - pultruded
3	113 yield Roving: 10 EPI - pultruded
4	E-TTX 2300 - pultruded
5	1oz Nexus Veil - pultruded

- Comparing Equivalent Flexural Stiffness Laminates (EI)
  - Same resin properties
  - Same surface veils
  - Same roving layer end count and yield
  - Only differences are the CFM and NCF layers
    - CFM: 2oz/ft^2
    - NCF: 23oz/yd^2 [+45°/90°/-45°] weft triaxial, 90° FAW dominant

NCF VS CFM

CFM Laminate #1	
1	1oz Nexus Veil - pultruded
2	M8643 CFM 2oz - pultruded
3	113 yield Roving: 10 EPI - pultruded
4	M8643 CFM 2oz - pultruded
5	1oz Nexus Veil - pultruded

NCF Laminate #1	
1	1oz Nexus Veil - pultruded
2	E-TTX 2300 - pultruded
3	113 yield Roving: 10 EPI - pultruded
4	E-TTX 2300 - pultruded
5	1oz Nexus Veil - pultruded

Total Wt.	1.302	1.101	lb/ft²
Thickness	0.157	0.118	in
Wf	47.438	63.724	%
Vf	30.294	45.771	%

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0° Modulus, Ex	2.919	3.931	Msi
90° Modulus, Ey	1.406	2.652	Msi
0° Flex. Modulus, Exf	1.163	1.994	Msi
90° Flex. Modulus, Eyf	1.003	2.585	Msi
Shear Modulus, Gxy	0.475	0.792	Msi

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VECTORPLY DIGITAL KNOWLEDGE CENTER

- Launched at CAMX 2021
- Online platform for composite education and information
  - VectorLam tutorial series
  - Processing tips and instruction
  - Product highlights and benefits
  - Customer features and case studies
  - Product line breakdowns
  - Engineering and testing capabilities explained
  - Growing addition designed to educate visitors

Thank you!

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