INTRODUCTION TO COMPOSITE MATERIALS

PRESENTED BY:

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PRESENTATION CONTENT

- DEFINITION
- TERMS
- HISTORY OF COMPOSITES
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- BUILDING A COMPOSITE
- MECHANICS
- APPLICATIONS

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TERMS

- Common terms used when discussing composite materials.
  - Filament
  - Fiber
  - Tow
  - Fabric
  - Fabric Architecture
  - Monomer
  - Resin/Polymer/Matrix
  - Hardener/Accelerator
  - Catalyst
  - Polymerization
  - Wet-out
  - Load Sharing
  - T_g
  - Tack-free Time
  - Cure Time
  - Polymer Knitting
  - Sizing

DEFINITION

- What is a composite material?
  - A composite is two or more distinct constituent materials combined to form a new material.
  - Mechanical properties of new material is determined by the rule of mixtures.
  - Examples are:
    - Concrete.
    - Fiber Reinforced Plastics.
    - Metal Matrix Composites.
  - Fibrous composites are often called Fiber Reinforced Plastics or FRP.

HISTORY OF COMPOSITES

- The earliest example of composite materials were found in Mesopotamia, Babylon and Egypt.
- This composite material was Adobe and is used around the world, even today.
- Concrete is also an example of a composite material.

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HISTORY OF COMPOSITES

- Composite materials have evolved into a new class of engineered materials referred to as Fiber Reinforced Plastics or FRP materials.
  – First use in Aerospace 1946 – 1950.
    - Aircraft wing using fiber glass, balsa wood, and shellac as the resin.
  – Other uses.
    - Defense.
    - Aerospace.
    - Sporting goods.
    - Transportation.
    - Infrastructure.

COMPOSITES USES

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CONSTITUENT MATERIALS

- Function of each material
  - Filaments are used to carry the mechanical load.
  - The resin is used to transfer loads between adjacent filaments and protect the fibers.
  - The properties of the resin is the determining factor in selecting a product based on temperature and environment.

CONSTITUENT MATERIALS

- Glass fibers (a fiber is defined as a collection of filaments) are formed by bundling individual filaments of glass into a tow. These tows contain 200 to 500 filaments with a diameter of 13µ to 24µ.
- Carbon fibers are formed into tow containing 1000 to 80000 filaments per tow. The industry nomenclature designates carbon fiber as 1K, 3K, 6K, 12K, 24K, 48K and 80K designating the size of the tow in 1000 filaments increments.
- Unlike glass filaments, carbon filaments are 7µ diameter for normal strain to failure carbon and 5µ diameter for high strain to failure.

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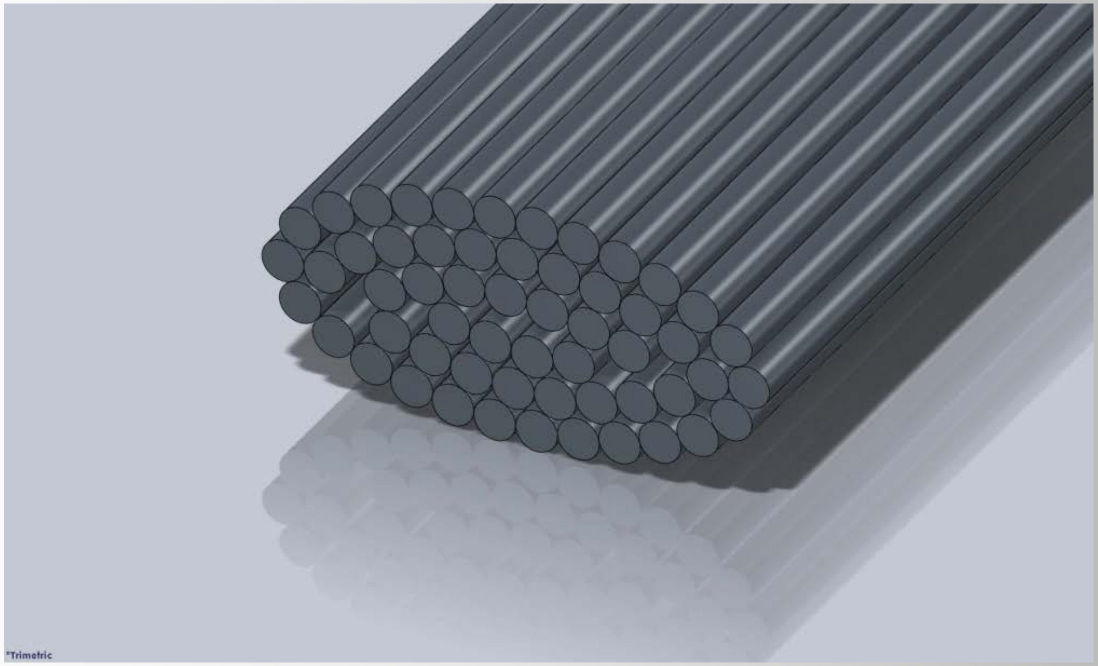
CONSTITUENT MATERIALS

- FIBER BUNDLE OR TOW



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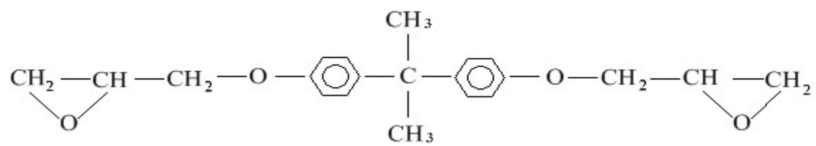
CONSTITUENT MATERIALS

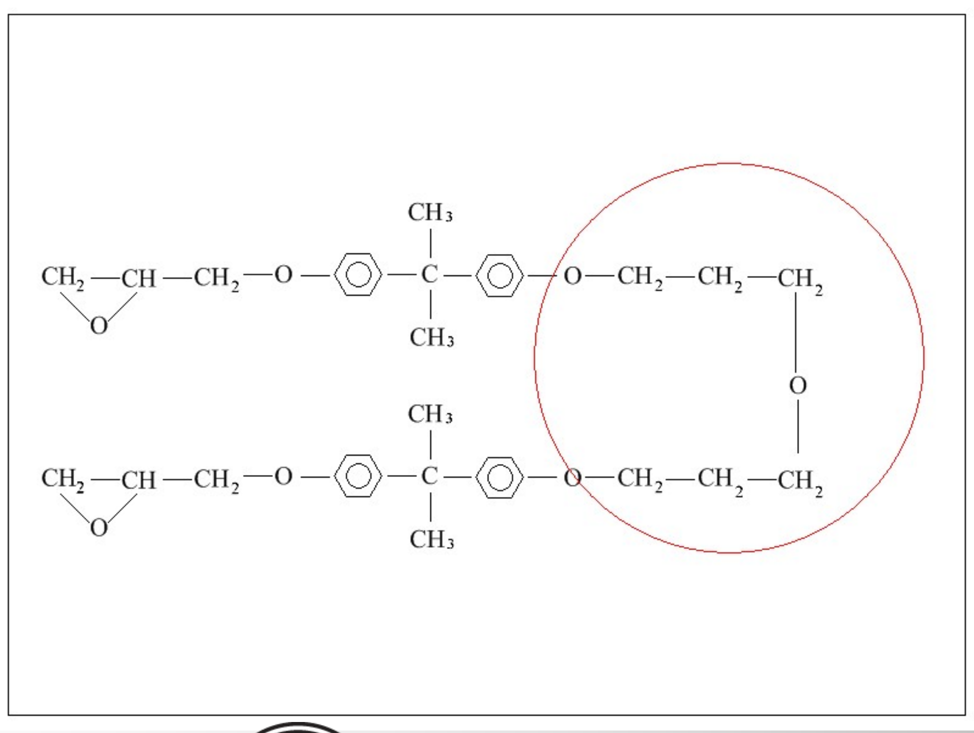
- EPOXY



DI-FUNCTIONAL EPOXY

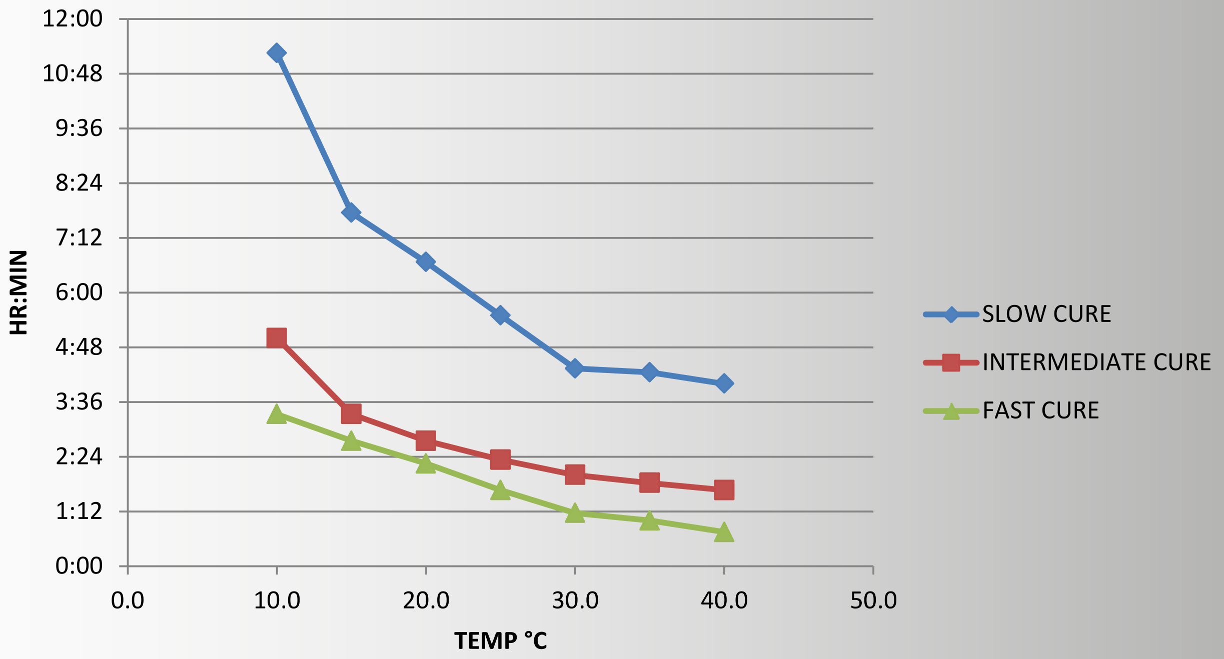
CONSTITUENT MATERIALS

- EPOXY REACTION PRODUCT



CONSTITUENT MATERIALS

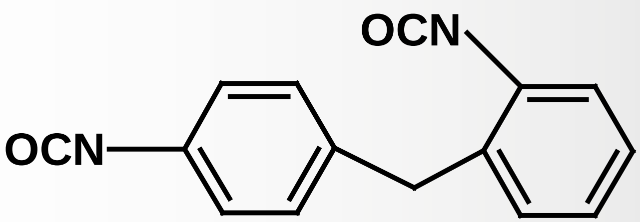
- EPOXY REACTION RATE



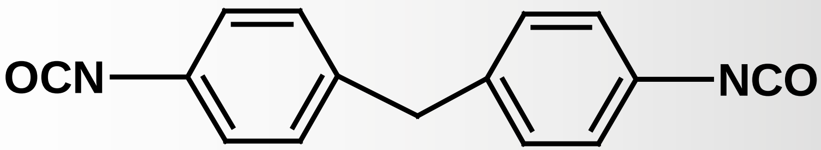
CONSTITUENT MATERAILS

MDI is a generic term for a mixture of isocyanates, among them:

- POLYURETHANE

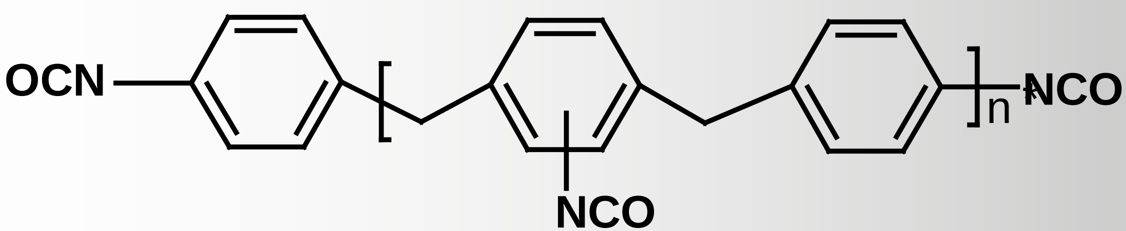


2,4’ Isomer



4,4’ Isomer

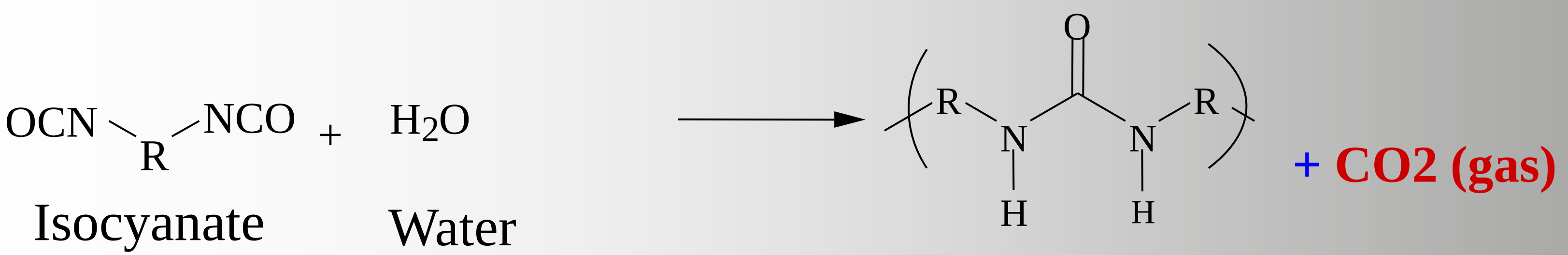
(Pure or Monomeric)



Polymeric

CONSTITUENT MATERIALS

- POLYURETHANE



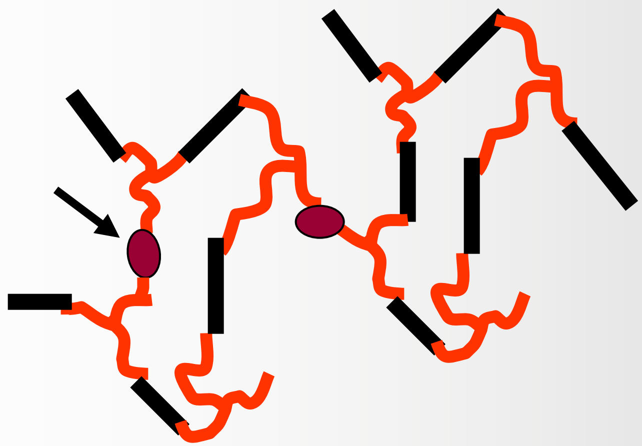
BASE MATERIALS

REACTION PRODUCTS

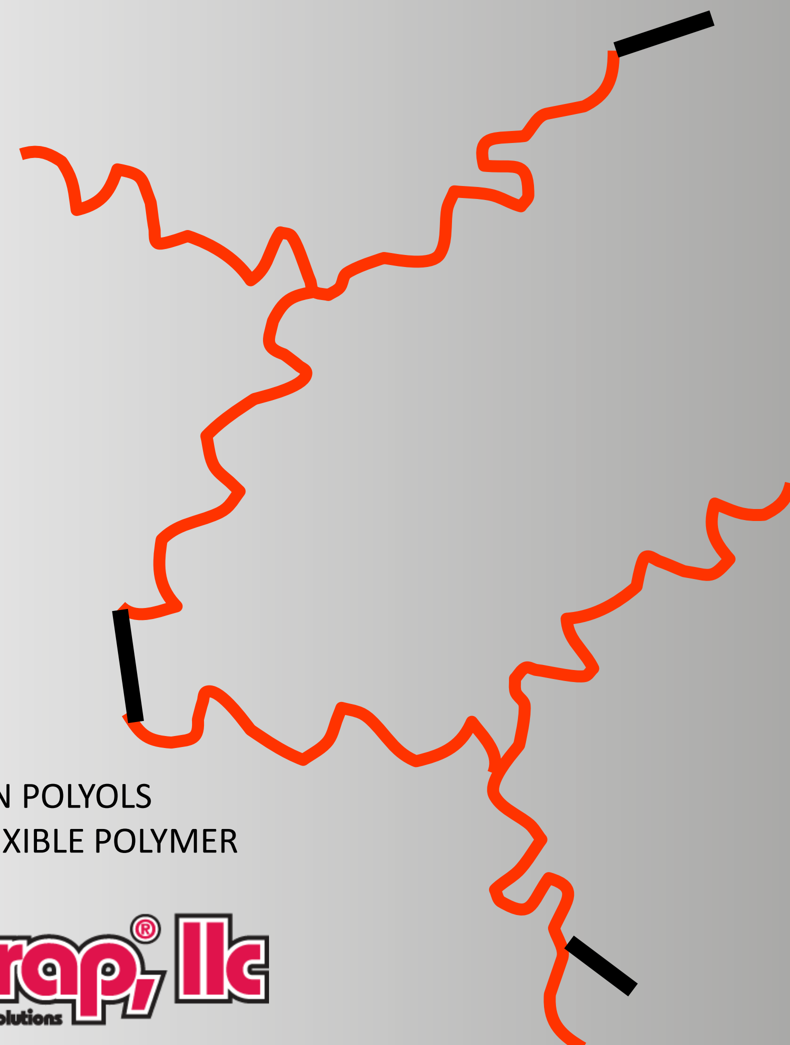
CONSTITUENT MATERIALS

POLYURETHANE

UREA ADDS
HARDNESS



SHORT CHAIN POLYOLS
LINKED TOGETHER WITH
ISOCYANATE TO MAKE
A STIFF POLYMER



LONG CHAIN POLYOLS
FORM A FLEXIBLE POLYMER

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ADVANTAGES AND DISADVANTAGES

EPOXY

- ADVANTAGES

- Higher mechanical properties.
- Higher temperature applications.
- Good impact resistance.
- Acid resistance.

- DISADVANTAGES

- Component mixing required in the field.
- Requires field impregnation.
- Application temperatures of ambient materials ≥ 10^{o} C.

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ADVANTAGES AND DISADVANTAGES

POLYURETHANE

- ADVANTAGES
- Resin content controlled at factory.
- Fiber wet – out complete.
- Water activated.
- Good impact resistance.
- Can be applied at lower. temperatures. (> 0^{o} C)

- DISADVANTAGES
- Lower mechanical properties compared to epoxy counterpart.
- Lower temperature resistance.

SELECTON CRITERIA

- USE TEMPERATURE
  - What is the temperature at time of installation?
  - What is the constant use temperature?
  - What temperature spikes will be seen?
  - What is the T_g of the resin system?
    - T_g is the glass transition temperature. It is the temperature a polymer goes from a solid to a plastic stage. PCC - 2 requires a de-rating of 50° F use verses the T_g of the resin.
    - Example:
    - Pipe operating temperature of 650°F, the T_g of the resin will need to be 700°F.

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SELECTON CRITERIA

- ENVIRONMENTAL
  - What is the material contained in the pipe?
  - Is the pipe buried?
    - What is the soil condition?
      Alkaline
      Acidic
      Petrochemical
  - Is the pipe above ground?
    - What are the atmospheric conditions around the pipe?
  - Is UV protection required?

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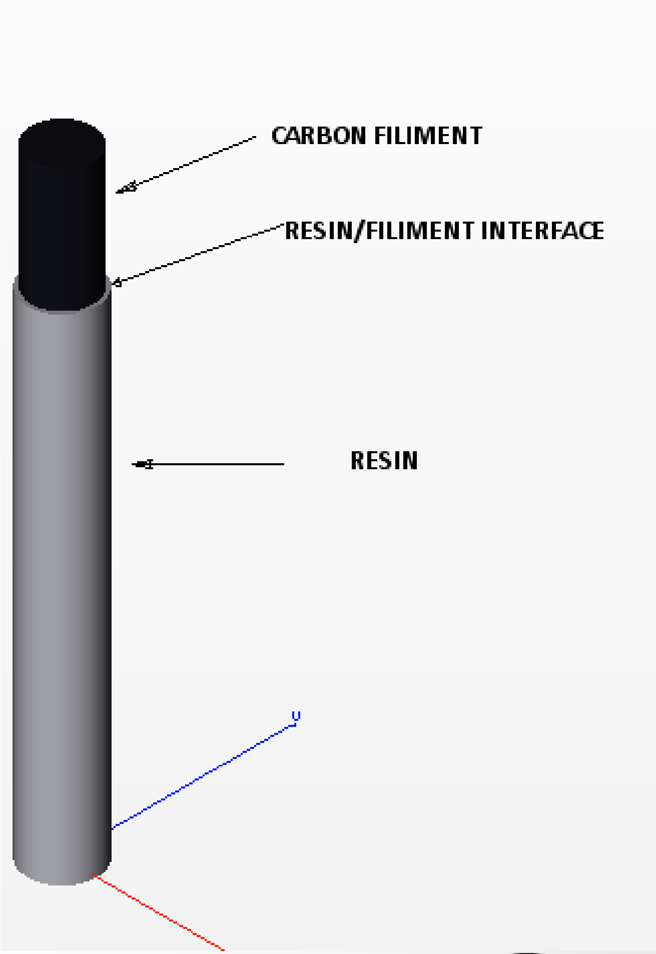
BUILDING A COMPOSITE



At the level of a single filament coming into contact with the matrix resin, the wetting qualities of the matrix resin and its affinity for the filament will dictate the most basic structural qualities of the final product.

Adhesion is a function of the contact angle and the liquid surface tension. For two bodies of material coming into contact:

$W_{adhesion} = \gamma (1 + \cos \theta)$

θ is the measured contact angle and γ is the surface tension of the liquid (surface tension of a liquid is not related to viscosity).

$W_{adhesion} = \gamma (1 + \cos \theta)$

For a liquid in contact with itself the work of cohesion is equal to the work of adhesion. For a liquid coming in contact with a solid, cos θ will always be ≤ 1. Thus, a liquid's work of adhesion to a solid substrate cannot be more than its own cohesion.

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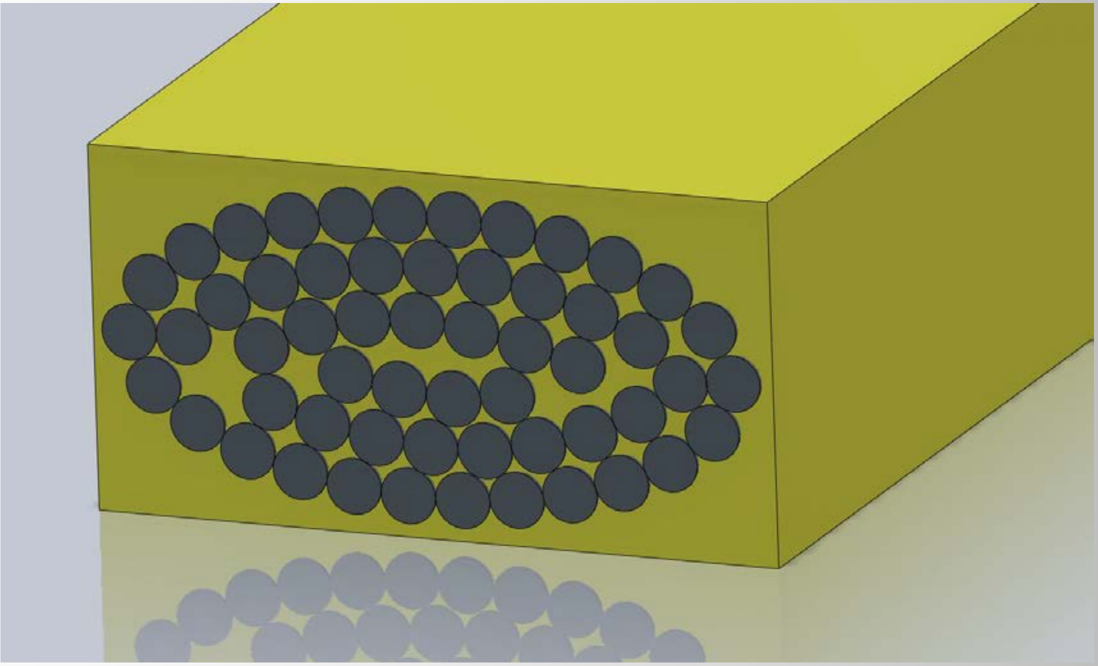
BUILDING A COMPOSITE

- IMPREGNATION BUILDING BLOCK



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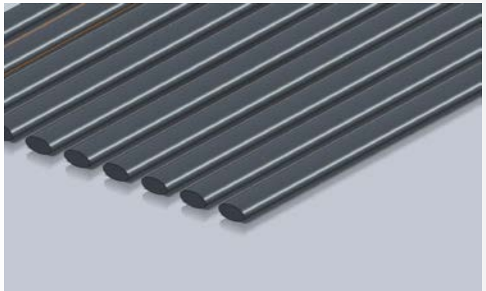
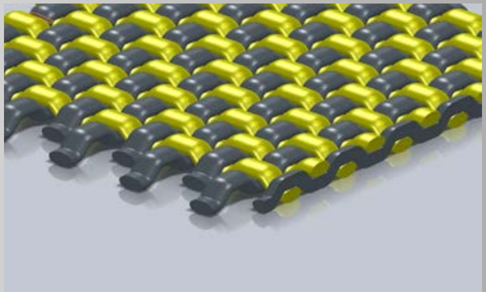
BUILDING A COMPOSITE

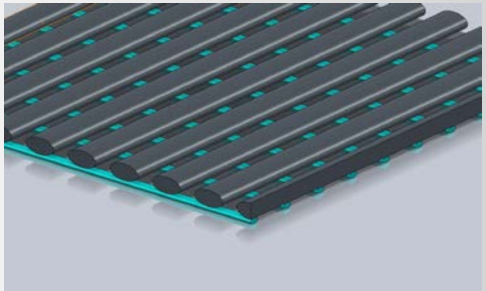
- FABRIC ARCHITECTURE



UNIDIRECTIONAL FABRIC



WOVEN FABRIC



STITCHED FABRIC

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MECHANICS

- MECHANICAL PROPERTIES COMPARISON

MECHANICAL PROPERTIES	UNITS	ASTM TEST METHOD	WOVEN FABRIC EPOXY RESIN	WOVEN FABRIC POLYURETHANE RESIN	STITCHED FABRIC EPOXY RESIN	STITCHED FABRIC POLYURETHANE RESIN	UNIDIRECTIONAL FABRIC EPOXY RESIN
TENSILE STRENGTH	PSI	D-3039-00	51066	37098	64932	48227	122550
TENSILE MODULUS	KSI	D-3039-00	3101	2423	3624	3574	11200
FLEXURAL STRENGTH	PSI	D-790-00	54748	29408	92459	42440	101021
FLEXURAL MODULUS	KSI	D-790-00	2471	2124	3335	3164	3889
MAXIMAN LOAD	LBF	D-2344	933	530	1017	580	530
INTERLAMINAR SHEAR STRENGTH	PSI	D-2344	6860	3208	5657	3223	6578
HARDNESS	SHORE D	D-2538	85-90	74-76	84-86	76-82	82-85

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MECHANICS

- The mechanical properties generated from flat panel and NOL ring testing are used in conjunction with the ASME PCC – 2 2011 engineering formulas to calculate the number of layers of composites required to repair a structure.

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MECHANICS

- For hoop stresses due to internal pressure the minimum repair laminate thickness, t_{min}, is given by:

$$t_{min} = \frac{D}{2s} \cdot \left(\frac{E_s}{E_c} \right) \cdot (P - P_s)$$ (equation 3)

- For axial stresses due to internal pressure, bending and axial thrust the minimum repair laminate thickness, t_{min} , is given by:

$$t_{min} = \frac{D}{2s} \cdot \left(\frac{E_s}{E_a} \right) \cdot \left(\frac{2F}{\pi D^2} - P_s \right)$$ (equation 4)

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APPLICATION STEPS

Review of Defect

Mark Area for Repair

Pipe Preparation

Apply Putty

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APPLICATION – cont.

Mix Coating

Apply to Pipe Surface

Wrap the Pipe

Compact Wrap

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CONCLUSION

- Successful composite repairs are based on the following:
  - Understanding constituent materials.
  - Selecting the composite material based on the environmental conditions and mechanical requirements.
  - Understanding the mechanical properties and how these are used to calculate the composite thickness as defined by ASME-PCC-2, 2011.
  - Understanding the installation requirements for any composite system.

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