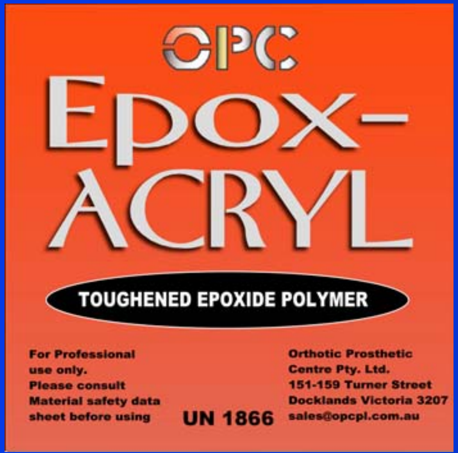
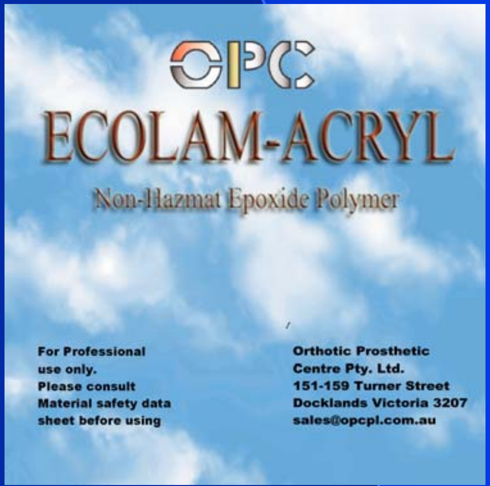
OPC

Thermoset composites and their use in O&P



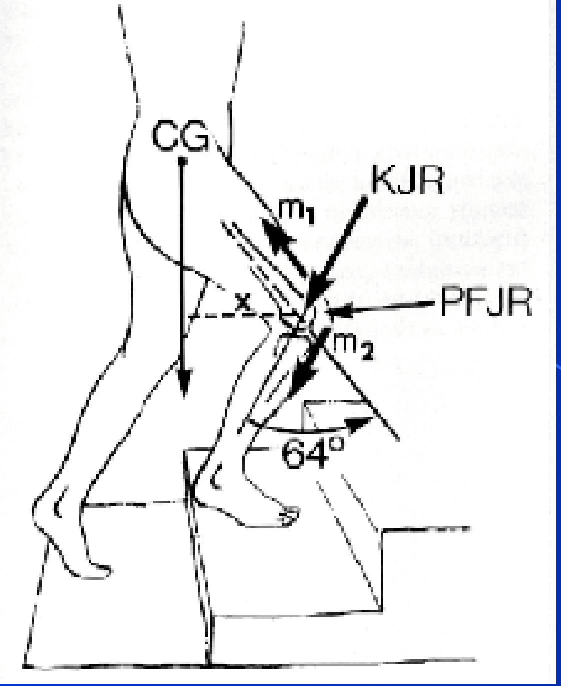


Why should an O&P practitioner care about material science

- Providing structurally sound devices
- Solving clinical challenges

Providing structurally sound devices

You will encounter devices that are constructed in a way that almost assures failure at some point.



Solving clinical challenges

The job of an O&P practitioner is to apply loads to the human body. The loads that are applied are dependent on the geometry of a device and the mechaical properties of it.

What is a Composite

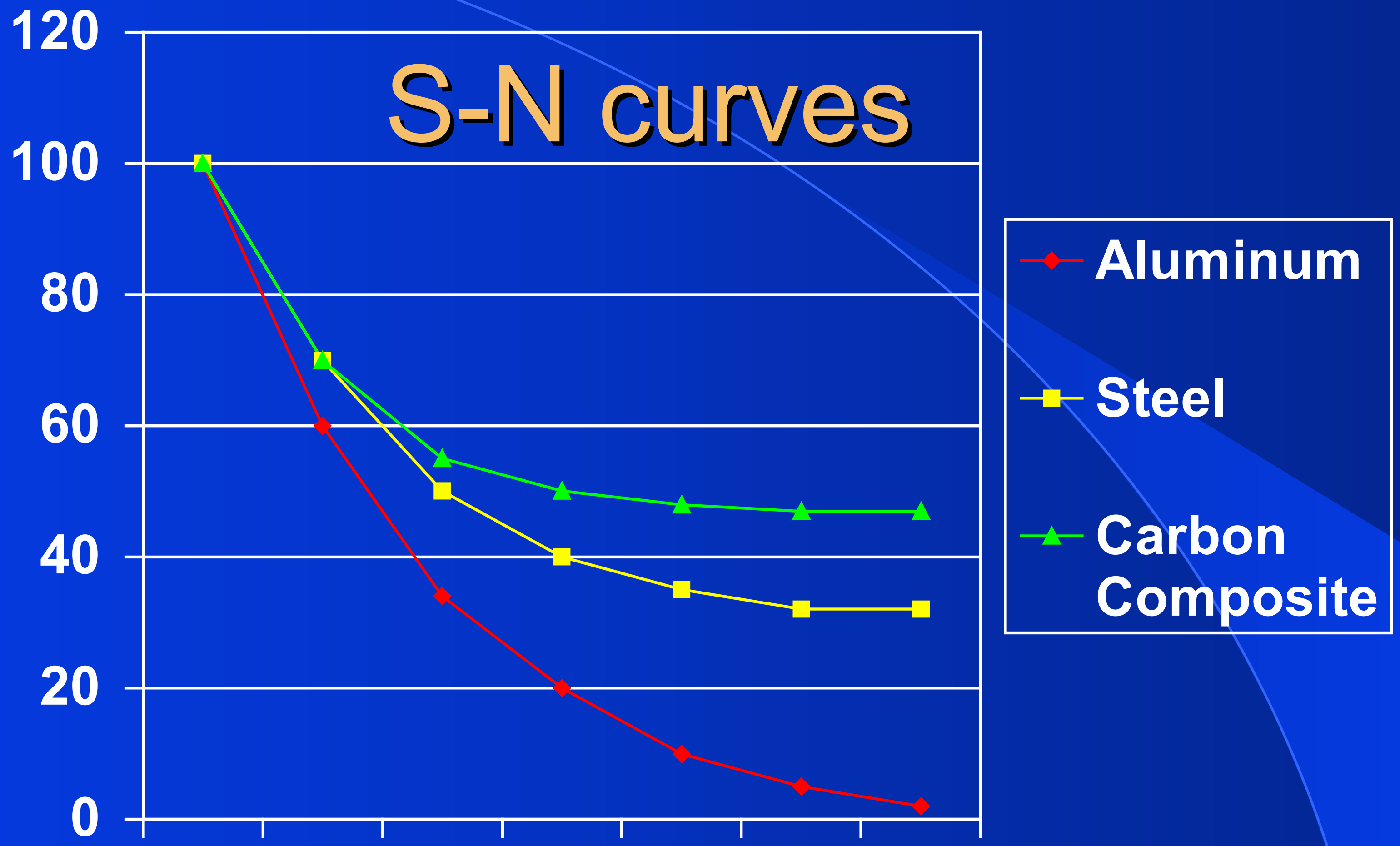
A composite is two or more materials with different properties, and when mixed they retain their individual identities, but act in concert to achieve different and often times more useful properties

Why Composites

- Fatigue Resistance
- Ability to be formed into complex shapes
- Corrosion resistance

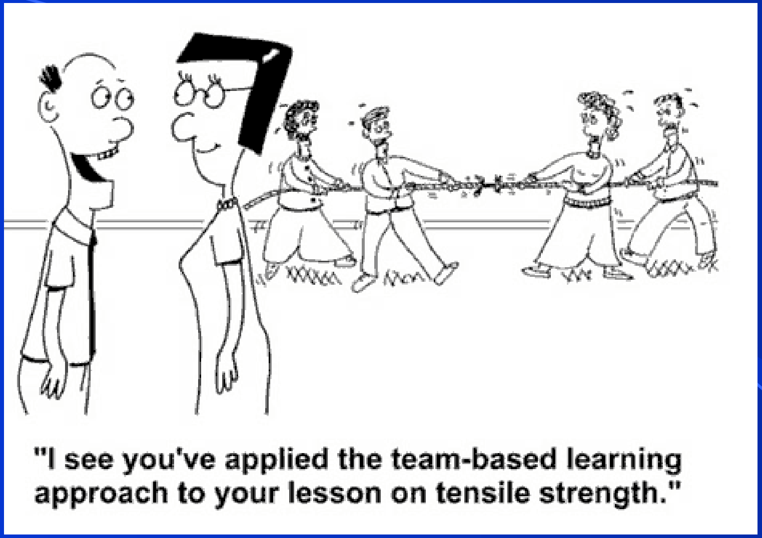
Fatigue Resistance

Ability to withstand repeated loading


S-N curves
120
100
80
60
40
20
0
Aluminum
Steel
Carbon Composite

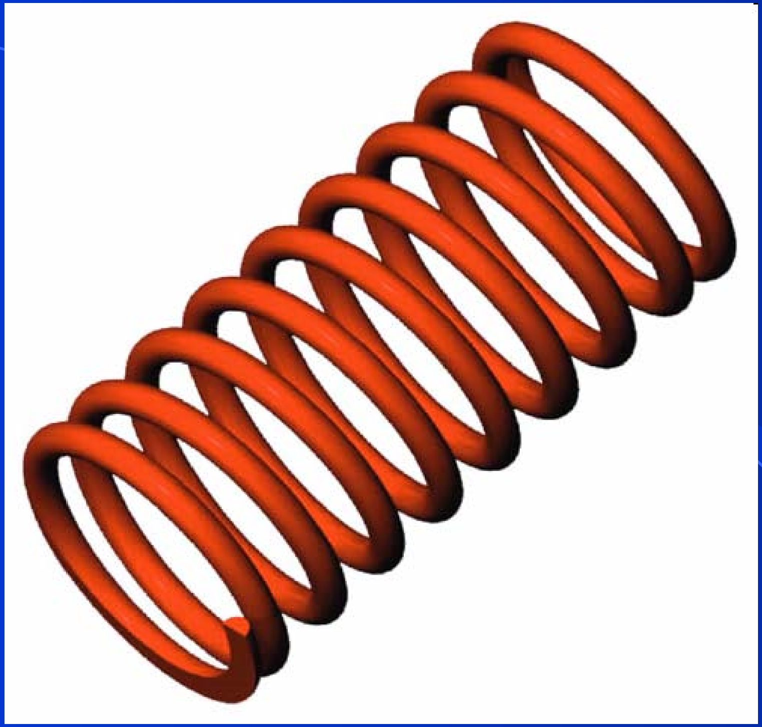
Engineering Terms

- Tensile Strength
- Modulus of Elasticity
- Density
- Stress
- Strain



Tensile strength

The maximal load per unit cross-sectional area. The pulling stress required to break a given specimen.



Modulus of Elasticity

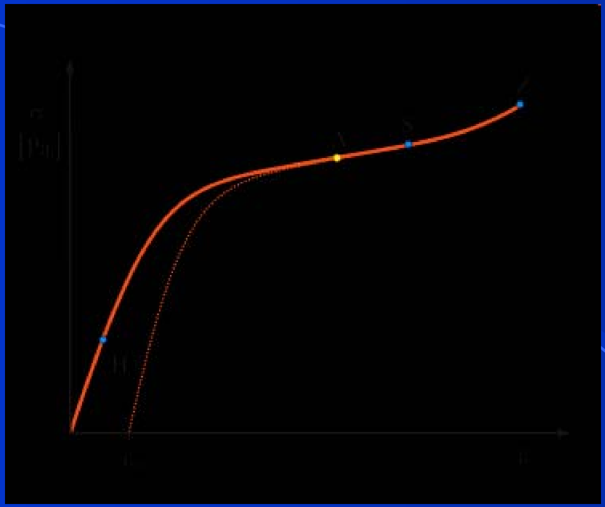
The ratio of stress to strain. How much a material stretches under a given load.

Density

The weight/mass per unit volume

Stress

The internal force per unit area that resists a change in size or shape of a body.



Strain

The change in dimensions of an object during a deformation.

Laminate constituents

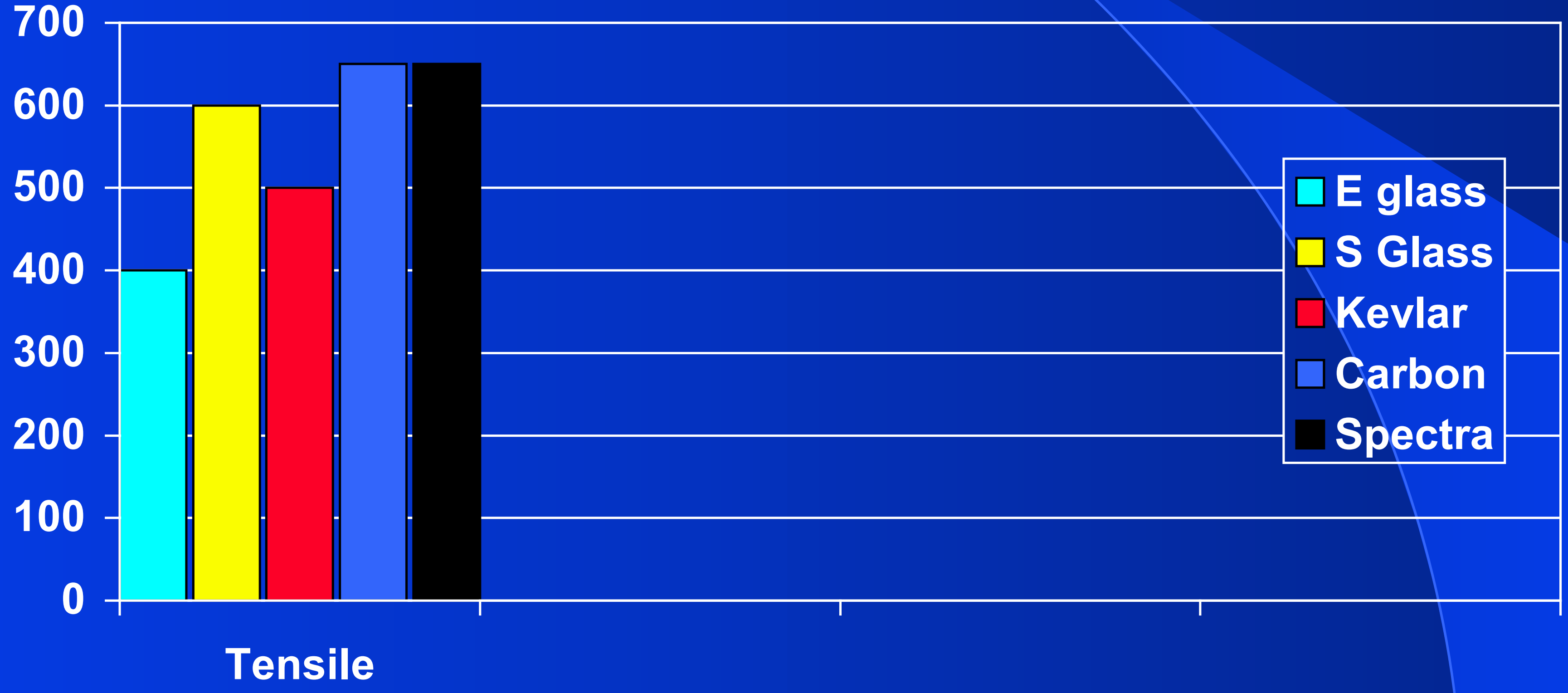
- Fiber
- Matrix (resin)

Fiber Types

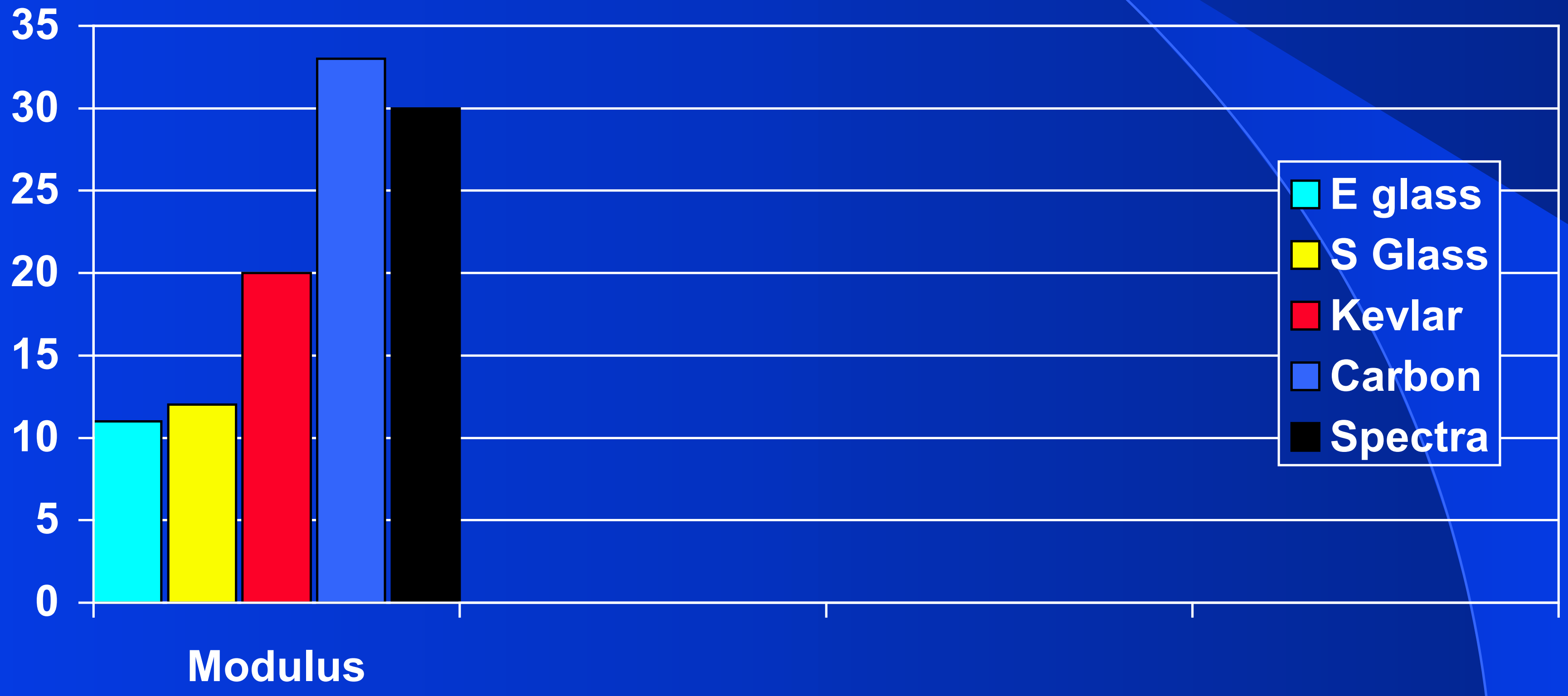
- E-Glass
- S-Glass
- Kevlar
- Carbon
- Spectra

Different fiber type can have very different properties and will transfer these properties to your laminate

Mechanicals of Various Fibers



Mechanicals of Various Fibers



Mechanicals of Various Fibers

Mechanicals of Fibers

	Tensile	Modulus	Density
E-Glass	400 ksi	11 msi	2.5 g/cc
S-Glass	600 ksi	12 msi	2.5 g/cc
Kevlar	500 ksi	20 msi	1.4 g/cc
Carbon	650 ksi	33 msi	1.7 g/cc
Spectra	650 ksi	30 msi	.98 g/cc

Fiber Forms

- Unidirectional
- 0-90 bi-directional cloth
- +45/-45 braid
- Knit




Resin Types

EAR1
EPOXY ACRYLIC
TOUGHENED LAMINATING RESIN
UN 1866
ECO
Epoxy-Acrylic Polymer
NexGen
Acsys
Nano-Res
Nano Toughened Polymer
Acsys
Acsys Orthopedic 2591 Pioneer Ave Vista, CA 92081 Sales@acsysortho.com

Thermoset resins

- Polyester
- Acrylics
- Modified epoxies
- Epoxies

Polyester Resins

- Unsaturated polymer dissolved in a vinyl monomer such as styrene.
- Cure via addition of catalyst
- Promoter or accelerators allow room temperature cure
- DEA or Diethylanaline used as promoter

Polyester Resins

- Lowest Cost
- Marginal fiber adhesion
- Low elongation to failure

Acrylic Resins

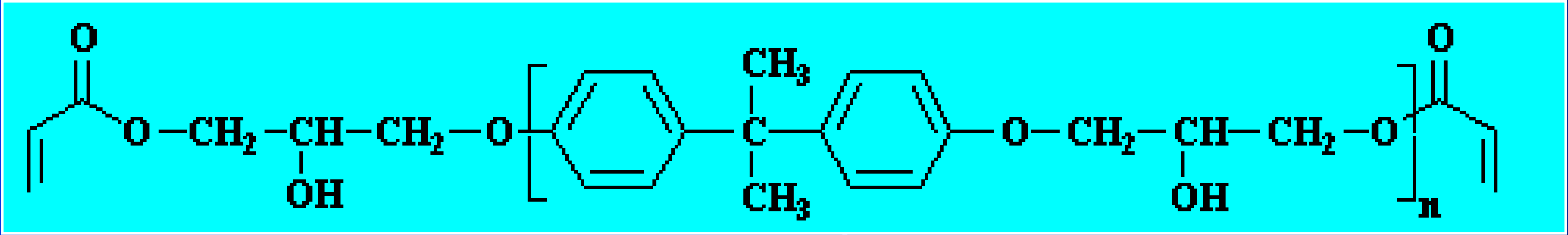
- Acrylate Monomers such as Methylmethacrylate
- Cured using a Catalyst such as Benzoyl Peroxide

Acrylic Resins

- High Cost
- Moderate fiber adhesion
- Somewhat Thermoplastic
- Low elongation to failure
- Liberate gas during cure cycle
- Most UV resistant

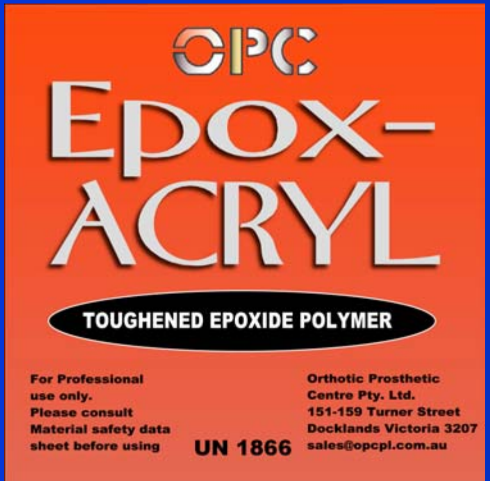
Modified Epoxies

- Vinyl acrylate groups grafted to epoxy back bone.
- Styrene monomer
- cured via a free radical reaction



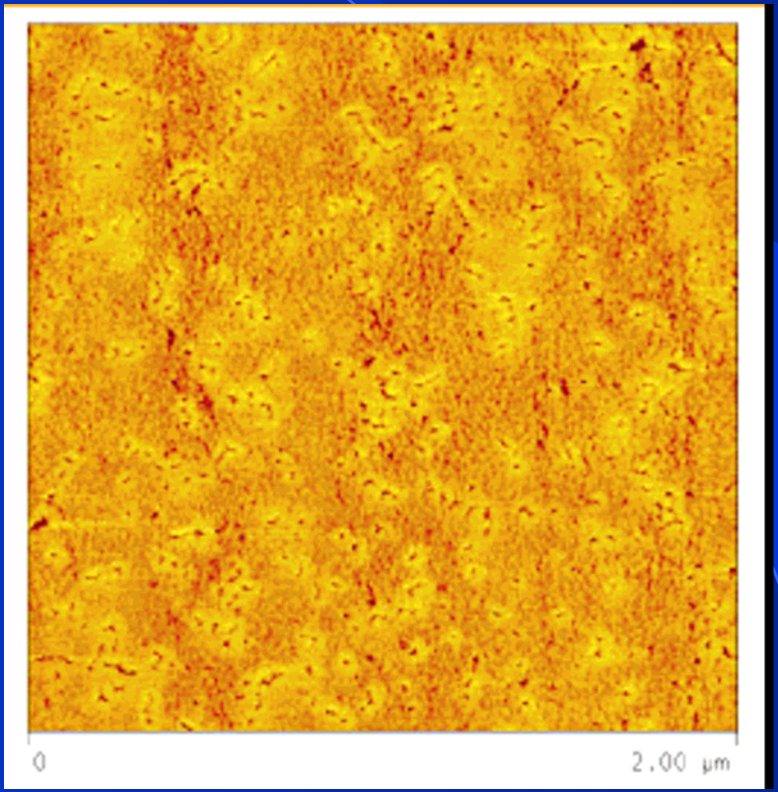
Modified Epoxies

- Easy to use
- Good fiber adhesion
- No gas liberation at cure
- High elongation to failure



Nano-Res

- Low Styrene
- High Modulus
- High Strength

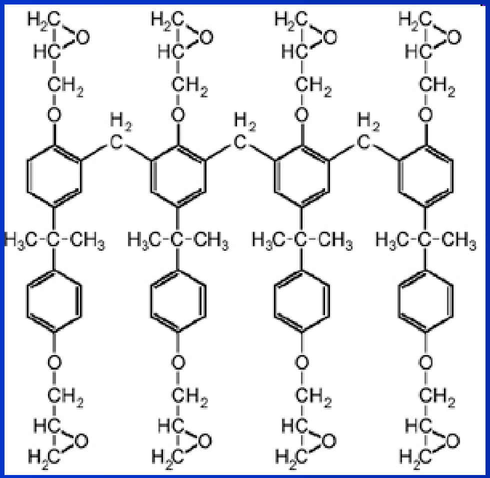


Epoxies

- Cured with amine hardener such as TETA(triethylenetetramine)
- Stoichiometry of reaction very important to give proper cure

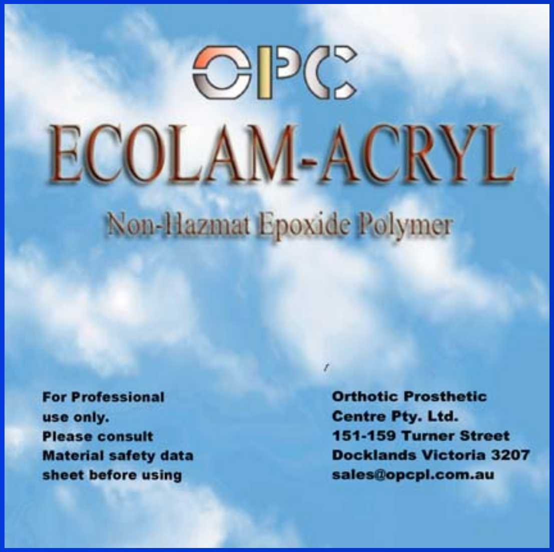
Epoxies

- Difficult to use
- Volume and temperature sensitive
- Best fiber adhesion



ECO Epoxy Acrylics

- Replaces Styrene monomer with environmentally friendly material
- Low Volatility and Odor
- Retains high strength and ease of Use



ECO Epoxy Acrylics

Styrene and Methylmethacrylate are hazardous air pollutants and are present in many laminating resins

Vapor Pressure

Styrene	5 mmHg
Methylmethacrylate	40 mmHg
ECO	.5 mmHg

Lamination Concerns

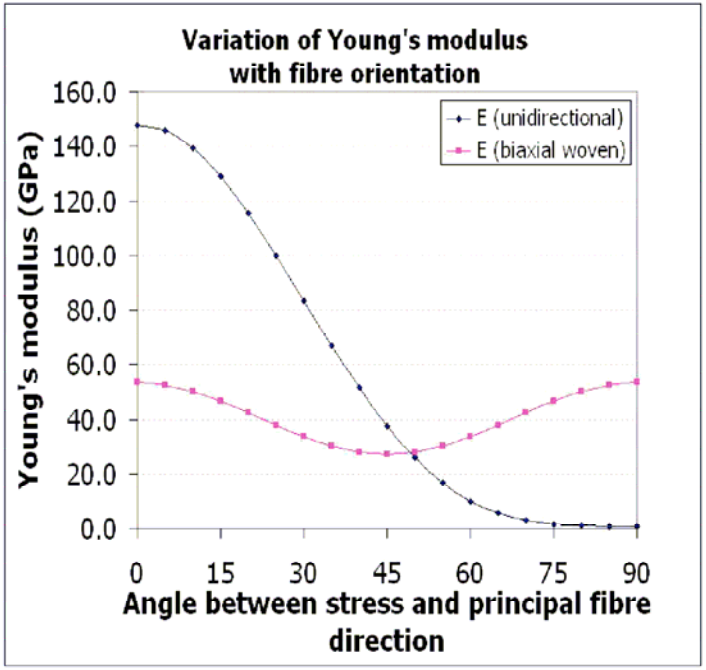
- Fiber orientation
- Stacking sequence
- Fiber wet out
- Lamination temperature
- Voids
- Fiber Crimp (bending)

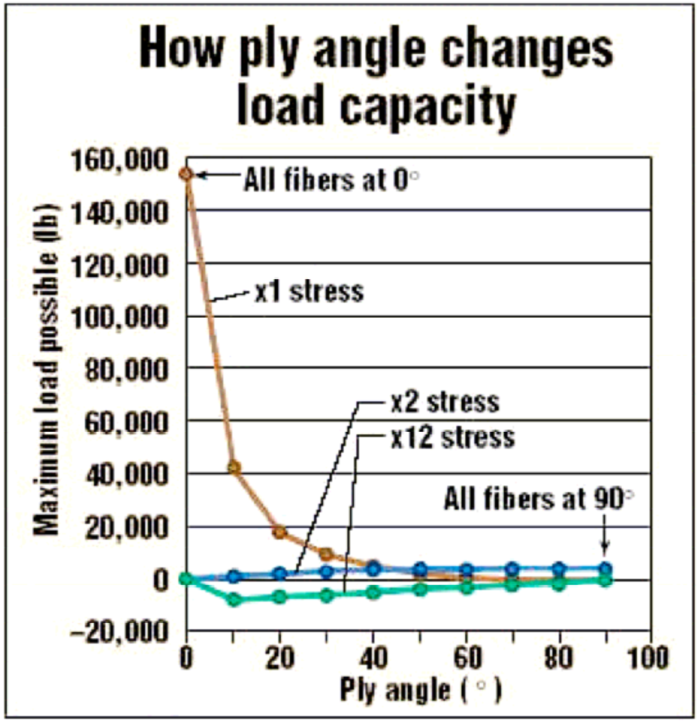
Fiber Orientation

A laminate is strongest when the loads are in the direction of the fibers, as the loads become perpendicular to the fibers the strength becomes matrix dominated

Effect of fiber orientation

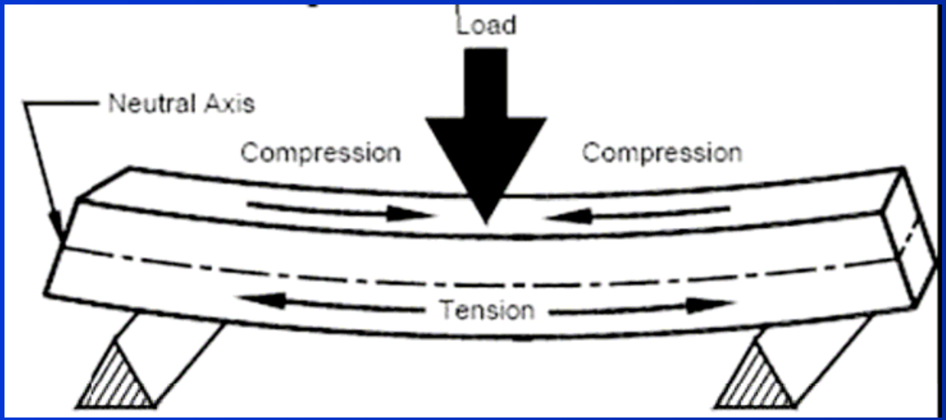
Figure 1





Stacking sequence

A laminate will be most rigid when the highest modulus fibers are far away from the neutral axis



Stacking sequence

The Laminator
Analysis of Composite Laminates Based on
Classical Laminated Plate Theory

Material 1: Generic E-Glass/Epoxy (composite.about.com)
Material 2: Generic IM6/Epoxy (composite.about.com)

Engineering Properties

Matl	E1	E2
1	5.700e+006	1.240e+006
2	2.940e+007	1.620e+006

Stacking Sequence

Layer	Matl	Ply Angle	Ply Thickness
1	2	0.0	1.000e-002
2	1	0.0	1.000e-002
3	1	0.0	1.000e-002
4	2	0.0	1.000e-002

Total Laminate Thickness : 4.000e-002

Apparent Laminate Stiffness Properties

EX	EXB
1.755e+007	2.644e+007

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Total Laminate Thickness : 4.000e-002

Apparent Laminate Stiffness Properties

EX	EXB
1.755e+007	8.663e+006

Fiber Wet Out

To get a good translation of fiber properties each fiber filament must be coated with resin

Lamination Temperature

Ideal conditions are between 20-26 degrees C

Voids

Voids can created a local debond and a potential cause of failure

Fiber Crimp

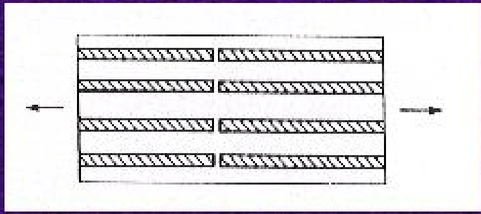
Fiber crimp can cause fiber buckling and will lower laminate mechanical properties.

Failure Analysis

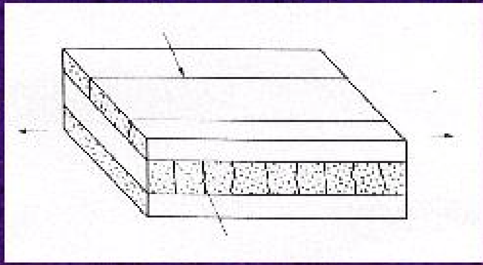
- Fiber Failure
- Resin Matrix Failure
- Delamination (debond failure)

Failure Modes of Composites

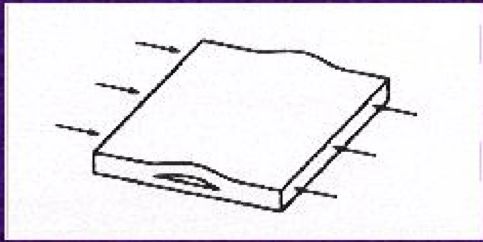
- Fibre failure
  (0° layer in tension)



- Matrix failure
  (90° layer in tension)



- Delamination



Thermoset laminate design

- Design Criteria
- Composite Theory

Displacement in a beam

$$\delta = \frac{4FL^3}{Ebt^3}$$

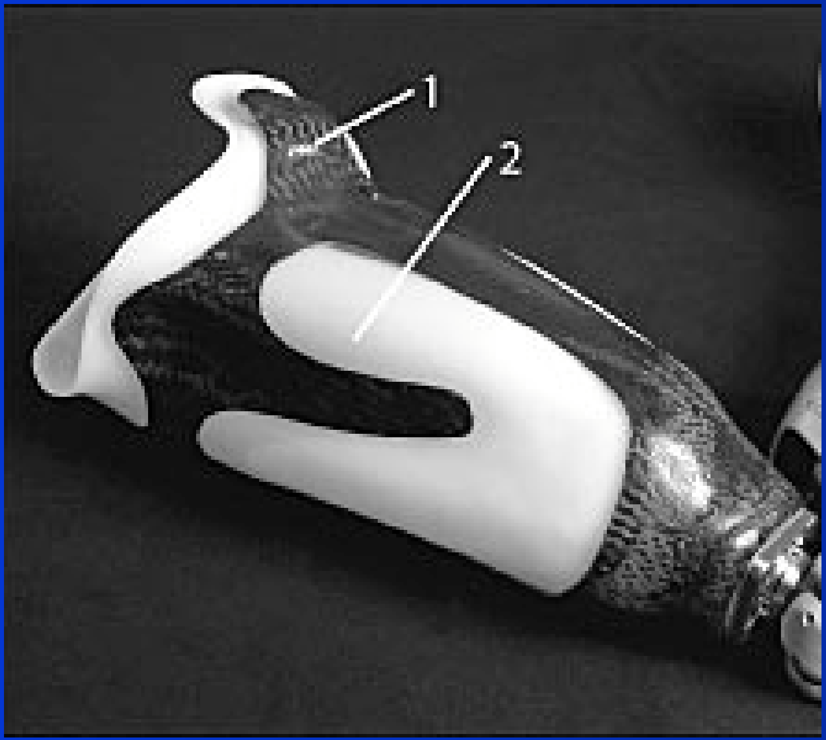
Design Scenarios

- Ischial Containment Socket Retainer
- Laminated AFO

Ischial containment socket

Need rigidity in areas to maintain "boney lock" while allowing design freedom to achieve maximum comfort

Ischial Containment Socket



Displacement in a beam

$$\delta = \frac{4FL^3}{Ebt^3}$$

Ways to accomplish design

- Use high modulus fibers
- Match fiber orientation to direction of loads
- Increase thickness of laminate
- Decrease length of bending zone
- Increase width of bending zone

Laminated AFO

Allow flexibility while maximizing high cycle fatigue strength

Engineering Terms

- Stress $\delta = F / A$
- Strain $\varepsilon = \Delta L / L$

Composites fatigue due to Microcrack propagation

The speed at which the cracks grow will depend on the amount of strain the laminate is subjected to

Infinite Life

Below 7500 micro strain carbon laminates can exhibit infinite life

Strain in a beam

$$\varepsilon = C\frac{t\delta}{L^3}$$

$$\varepsilon = C\frac{t\delta}{L^3}$$

$$\delta = \frac{4FL^3}{Ebt^3}$$

Decreasing the thickness will decrease the strain but will also result in a cubic increase in the deflection

Force	Beam Length	Modulus	Width	Thickness
1000000	10	10000000	5	2

Strain	0.02	$\varepsilon = C \frac{t\delta}{L^3}$
Displacement	10	$\delta = \frac{4FL^3}{Ebt^3}$

Force	Beam Length	Modulus	Width	Thickness
1000000	10	10000000	5	4

Strain	0.005	$\varepsilon = C \frac{t\delta}{L^3}$
Displacement	1.25	$\delta = \frac{4FL^3}{Ebt^3}$

Force	Beam Length	Modulus	Width	Thickness
1000000	10	1249999.251	5	4

Strain	0.040000024	$\varepsilon = C \frac{t \delta}{L^3}$
Displacement	10.00000599	$\delta = \frac{4 FL^3}{Ebt^3}$

Force	Beam Length	Modulus	Width	Thickness
1000000	10	20000000	5	1.587397327

Strain 0.015874085

$$\varepsilon = C \frac{t\delta}{L^3}$$

$$\delta = \frac{4FL^3}{Ebt^3}$$

Displacement 10.00007041

To survive laminate must be as thin and rigid as possible

use highest modulus design and minimize thickness

Ways to accomplish design

- Use high modulus fibers
- Use on axis fiber orientation
- Use as little material as possible