CAU2014

Analysis and Evaluation of Fiberglass-Reinforced Plastic Pipe

Using CAESAR II

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Agenda

- **Fiberglass pipe**
- Design using ISO 14692
- Using C2

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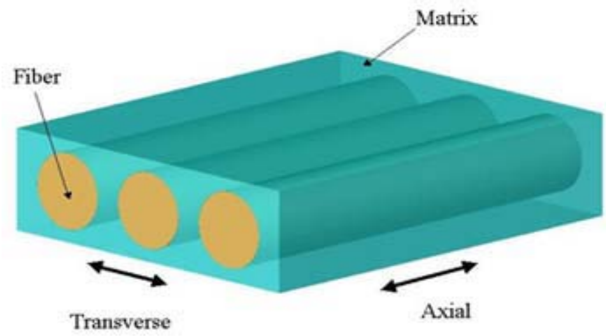
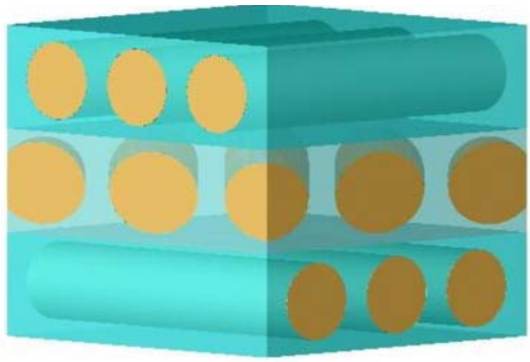
How do these materials together define the Mechanical properties?

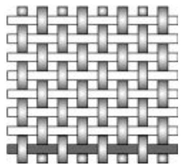




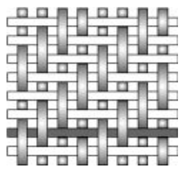
Laminate

Glass appearance in many ways

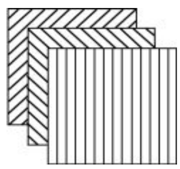
- Continuous roving
  - Direct
  - Assembled
- Chopped strand mats
- Continuous strand mats
- Woven fabrics
  - Unidirectional
  - Bi-directional
  - Multi-axial
- Knitted



Plain weave



twill weave



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Micro level analysis

- Failure modes to be evaluated:
  - Failure of the fiber
  - Failure of the coupling agent layer
  - Failure of the matrix
  - Failure of the fiber-coupling agent bond
  - Failure of the coupling agent matrix bond

- Reduced failure mode evaluation (lack of detailed knowledge of 2, 4 and 5)
  - Fiber failure
  - Matrix failure
  - Fiber-matrix interface failure

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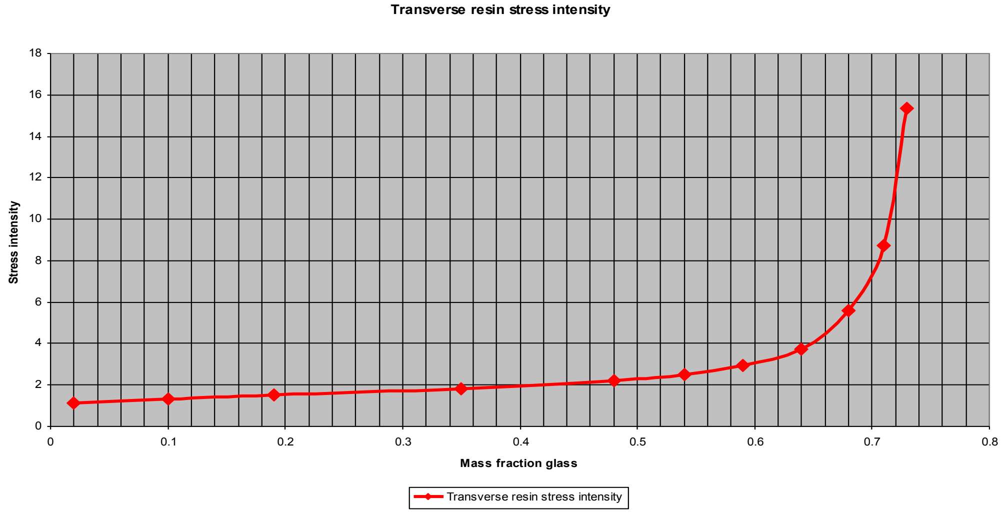
Stress level dependent on glass resin ratio

- Maximizing glass- resin ratio is not favorable for loads perpendicular to the glass
- For larger glass resin ratios resin bridges become the weak spot



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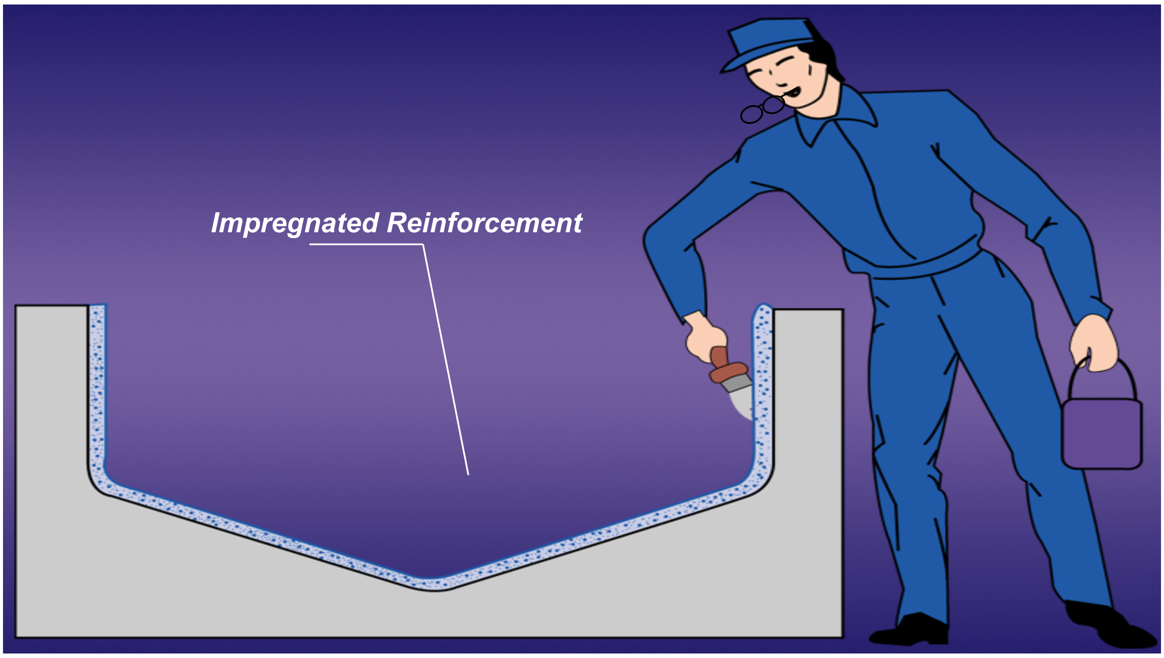
Macro level analysis instead of Micro level

- Micro level analysis
  - Feasible in concept
  - Not feasible in practice since many fibers randomly distributed and oriented

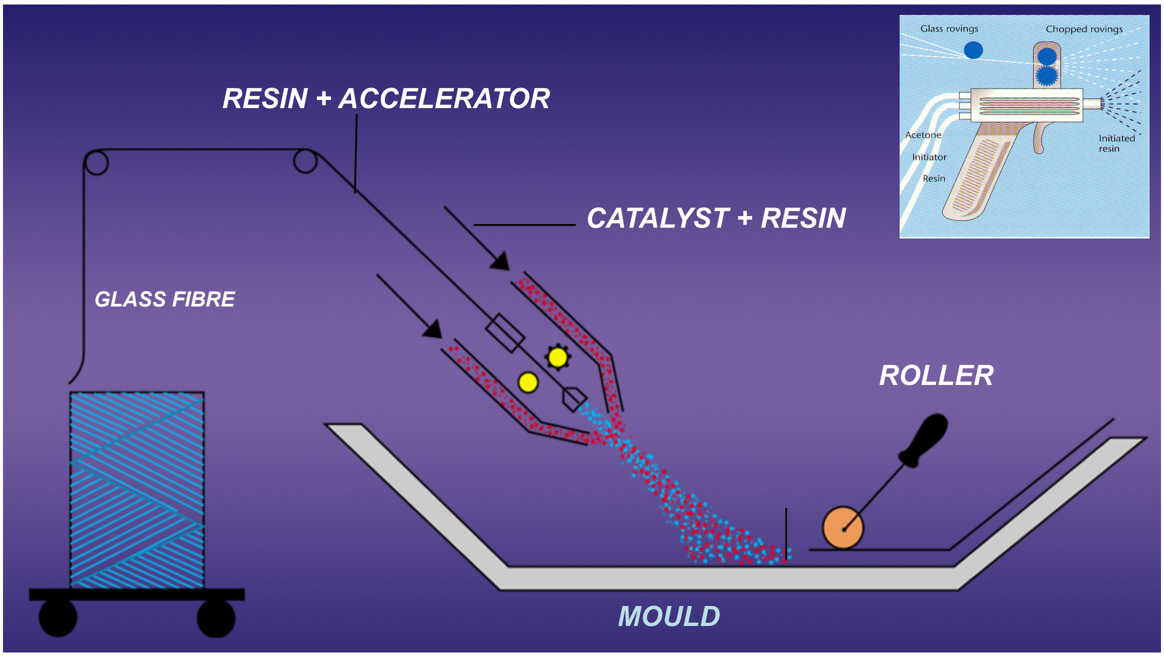
- Mini level analysis.
  - Evaluation of individual laminate layers
  - Laminate layer is considered a continuum with material properties and failure modes
  - Assessment by averaging over cross-section.

- Macro level analysis. (actual state of the art)
  - Evaluation of components made from multiple laminate layers
  - Series of layers act as a homogeneous material with estimated properties based on layer properties and winding angle
  - Failure analysis based on equivalent stress

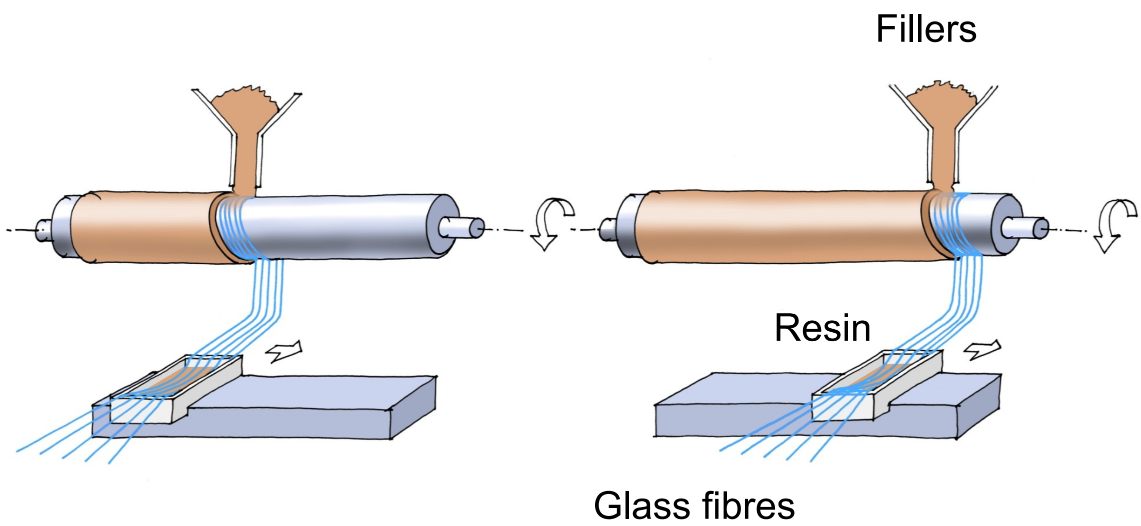
Hand Lay-up processing technique



Spray-up processing technique



Filament winding processing technique



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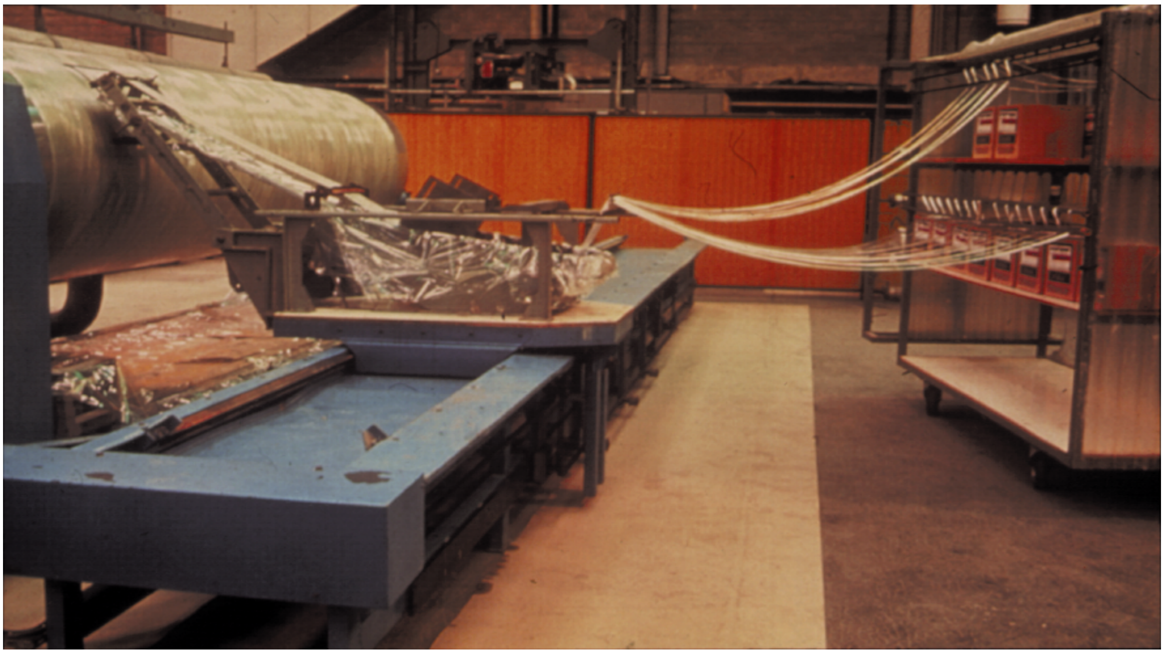
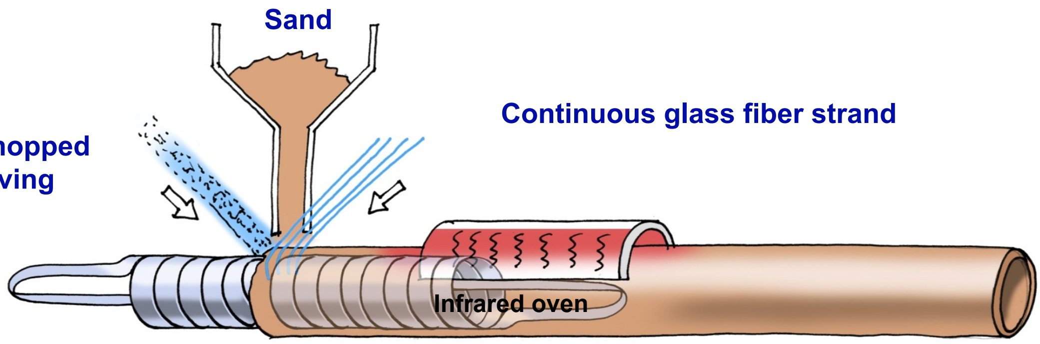
Filament winding in action



Helical winding processing technique

Continuous filament winding processing technique



Diameters from 100 through 4000mm

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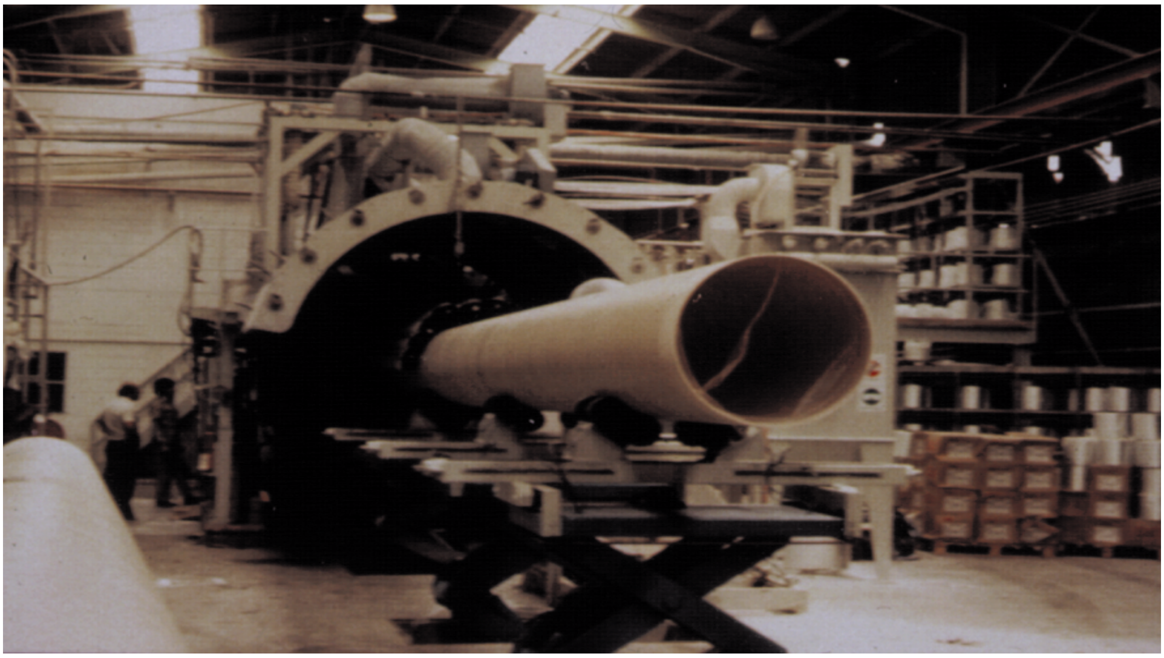
Continuous filament winding in action



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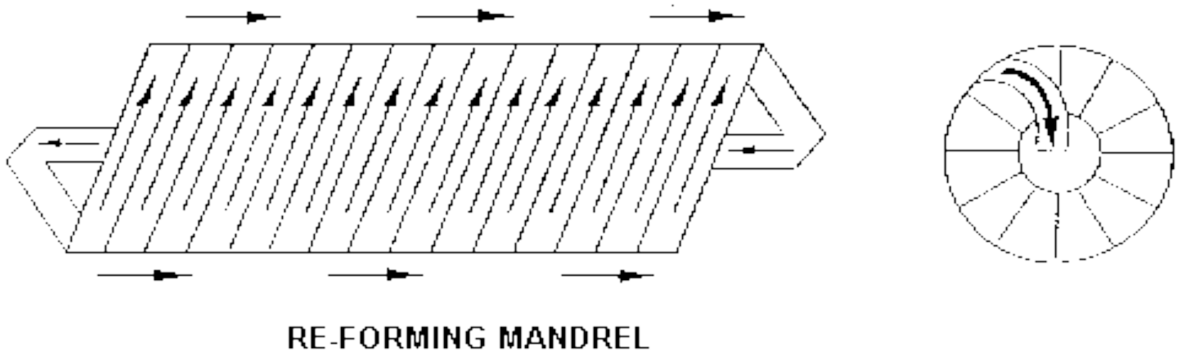
Continuous filament winding in action



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Continuous filament winding in action

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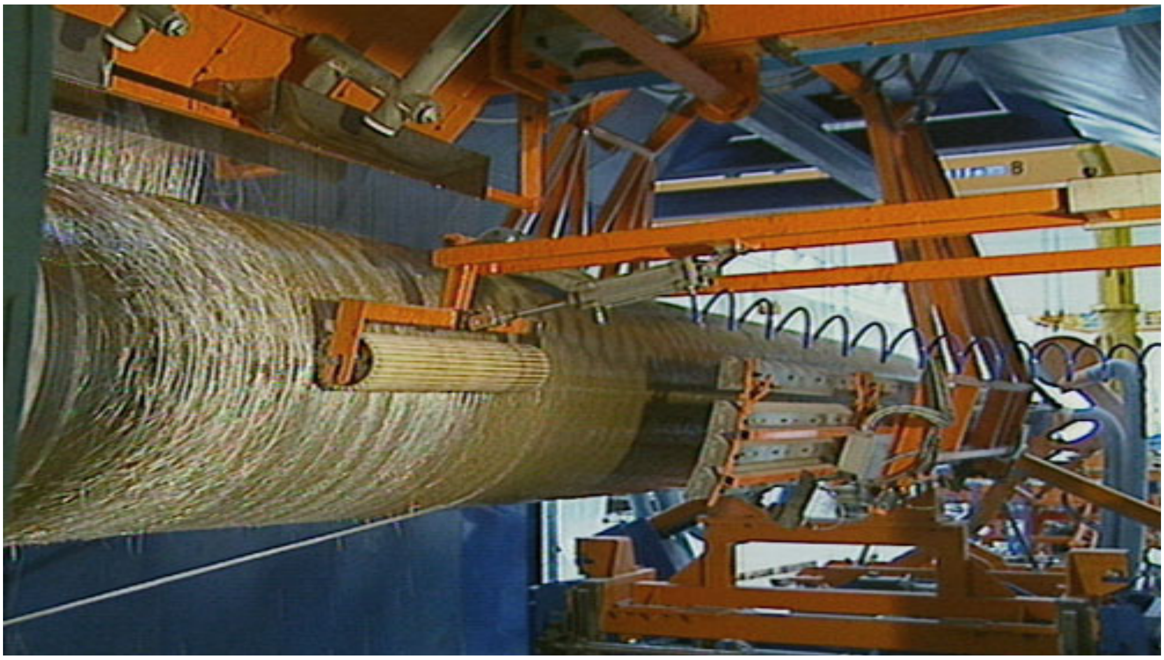
Continuous filament winding in action



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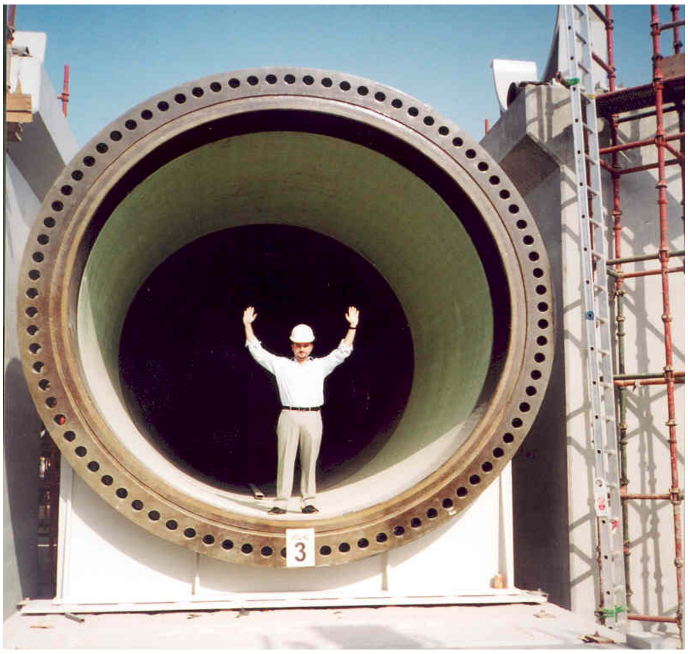
Before looking at the various design aspects first a little Fiberglass Quiz



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How does typical specific thermal expansion coefficients compare?

	α [μm/m/°C]
Stainless Steel	16.5
Carbon Steel	11.0
PVC	72.0
Polyethelene	120.0
Fiberglass	?

α = 50.0 [μm/m/°C]

α = 20.0 [μm/m/°C]

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α = 50.0 [μm/m/°C]

α = 20.0 [μm/m/°C]

CORRECT

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How does the typical (volumetric) Elasticity of fiberglass compare?

	E [MPa]
Ductile iron	180.000
Steel	200.000
PVC	3.000
Fiberglass	?

E = 20.000 MPa

E = 2.000 MPa

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	E [MPa]
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E = 20.000 MPa

E = 2.000 MPa

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What is the GRP required free bend leg length?

Required free bend leg length for accommodation of the expansion.

Parameters:
- *Internal pressure:* 20 Barg.
- *Delta Temp.:* 60 °C
- *Expanding leg:* 50 m

DIAMETER	GRP	STEEL
150mm	?	4m
200mm	?	4.6m

GRP: 5m and 5.5m

GRP: 7m and 8m

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GRP: 5m and 5.5m

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What is the typical wave speed in a Fiberglass pipe?

$$a = \sqrt{\frac{\frac{K}{\rho}}{1 + \frac{D}{t}\frac{K}{E}}}$$

Steel: 1000 - 1400m/s

GRP: 300 – 500m/s

GRP: 1300 – 1500m/s

K = fluid modulus of elasticity [Pa]

ρ = fluid density [kg/m^3]

D = pipe diameter [mm]

t = pipe wall thickness [mm]

E = pipe modulus of elasticity [Pa]

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K = fluid modulus of elasticity [Pa]

ρ = fluid density [kg/m^3]

D = pipe diameter [mm]

t = pipe wall thickness [mm]

E = pipe modulus of elasticity [Pa]

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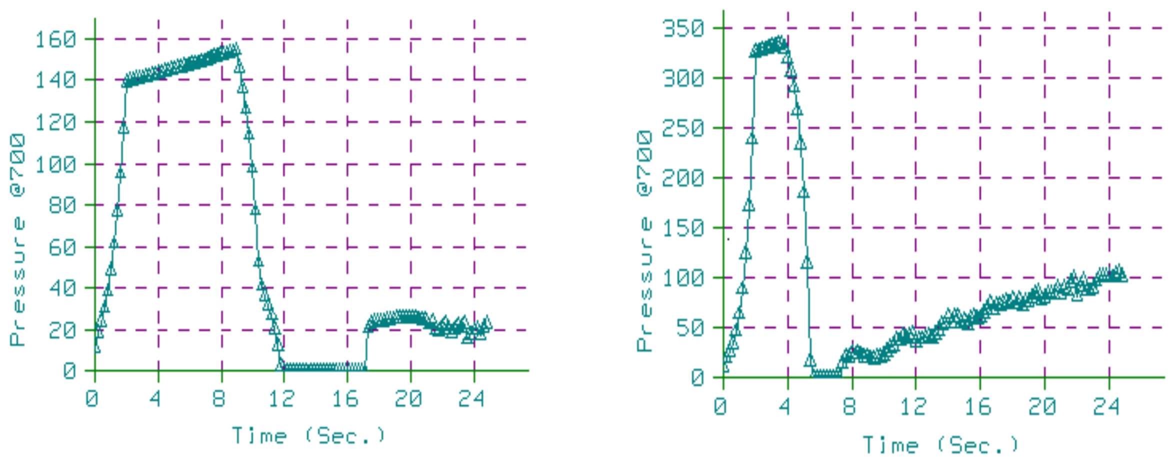
Surge/Pressure Effects in GRP pipe in general are less than in metal pipe

FIBERGLASS | **STEEL**



Pressure time history at valve (valve closure time: 2 secs)

How does the effective material wall roughness of fiberglass compare?

	ε [mm]
Ductile iron	0.03-0.1
Steel	0.1-0.3
PVC	0.05
Fiberglass	?

ε = 0.05 mm

ε = 0.001 mm

How does the effective material wall roughness of fiberglass compare?

	ε [mm]
Ductile iron	0.03-0.1
Steel	0.1-0.3
PVC	0.05
Fiberglass	?

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ε = 0.05 mm

ε = 0.001 mm

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How large is the effective material axial strain due to internal pressure ?

	ε [mm]
Ductile iron	0.005-0.01
Steel	0.005-0.01
Fiberglass	?

ε = 0.15 %

ε = 0.015 %

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How large is the typical material axial strain due to internal pressure ?

	ε [mm]
Ductile iron	0.005-0.01
Steel	0.005-0.01
Fiberglass	?

CORRECT

ε = 0.15 %

ε = 0.015 %

For σ_a = 18 MPa ε_p = 18/12000 = 0.15%
For ΔT = 75°C= $\varepsilon_T = 20 * 75 * 10^{-6}$ = 0.15 %

Agenda

- Fiberglass pipe
- **Design using ISO 14692**
- Using C2

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ISO 14692 part 2 requires qualification of pipe and components

Small bore products (typically pipe):

- Long term regression test (ASTM D 2992)
- Delivers long-term strength
- Takes approximately two years

Example of a burst test

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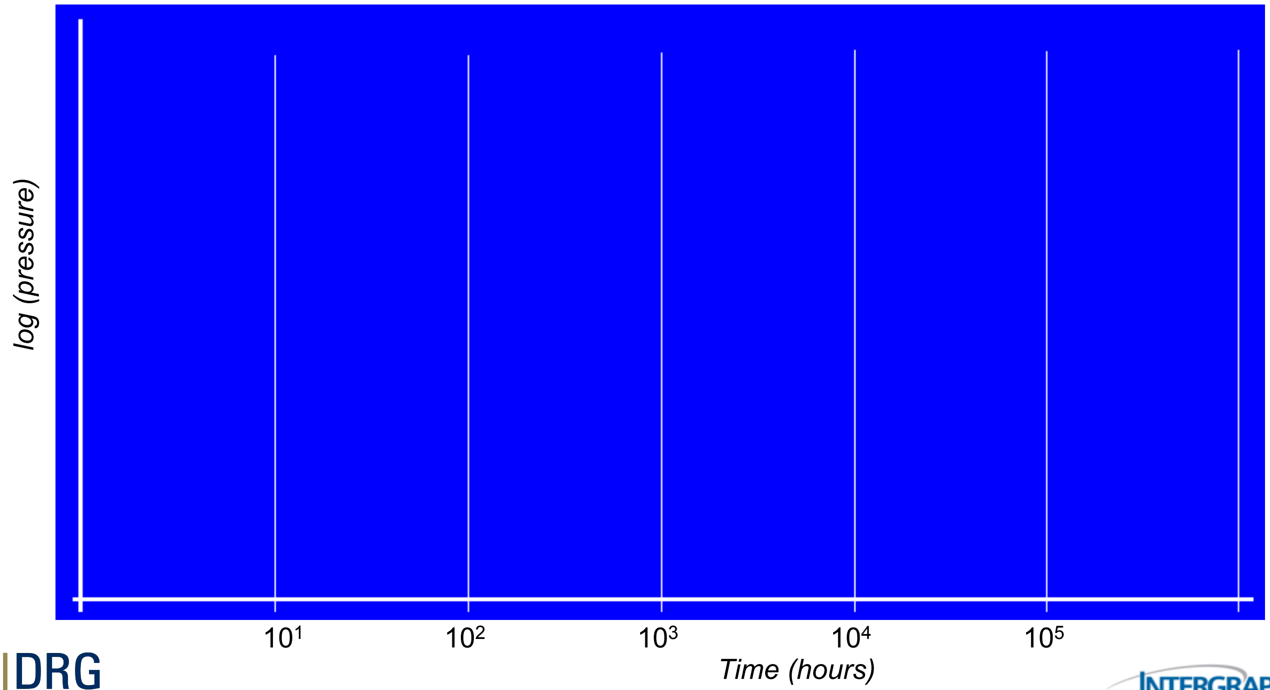
Qualification of GRP – ASTM D 2992



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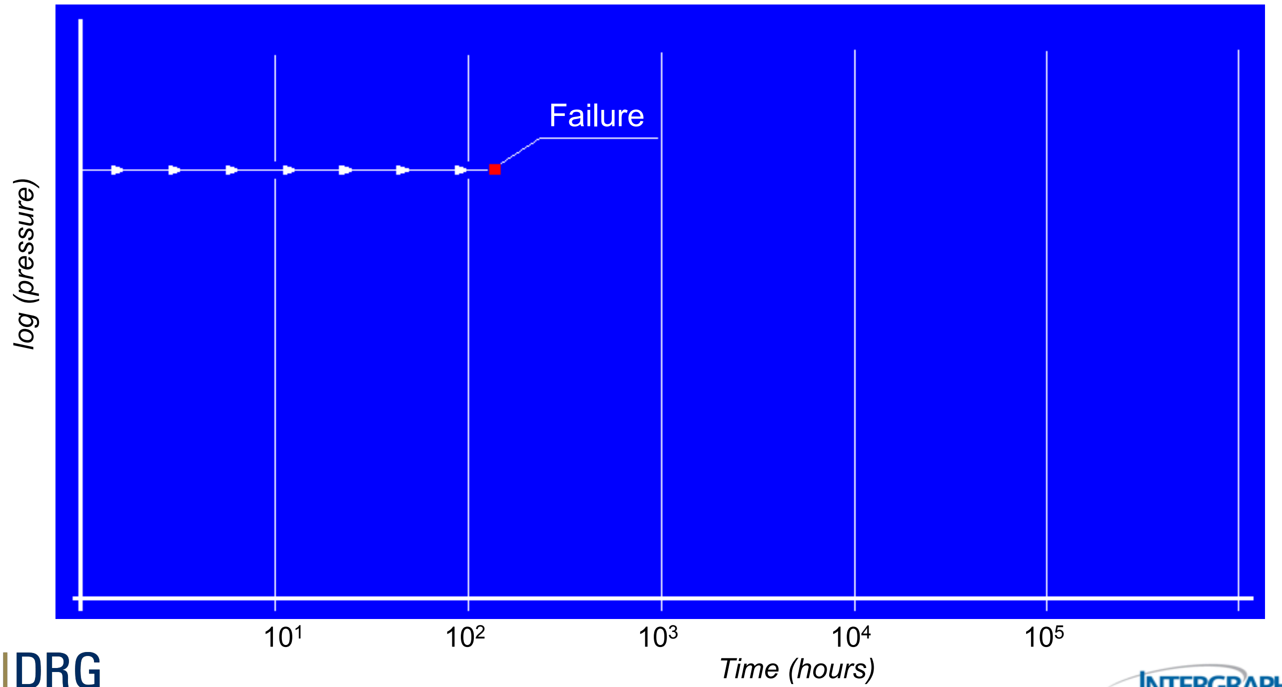
Qualification of GRP – ASTM D 2992



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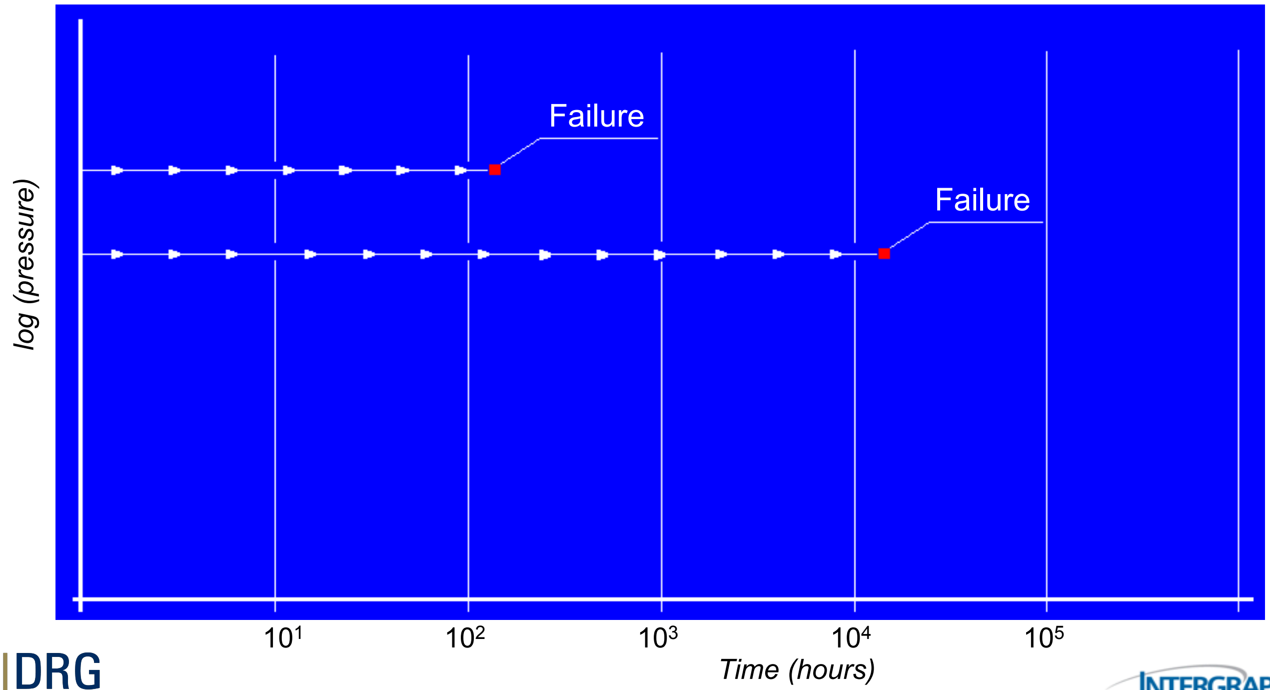

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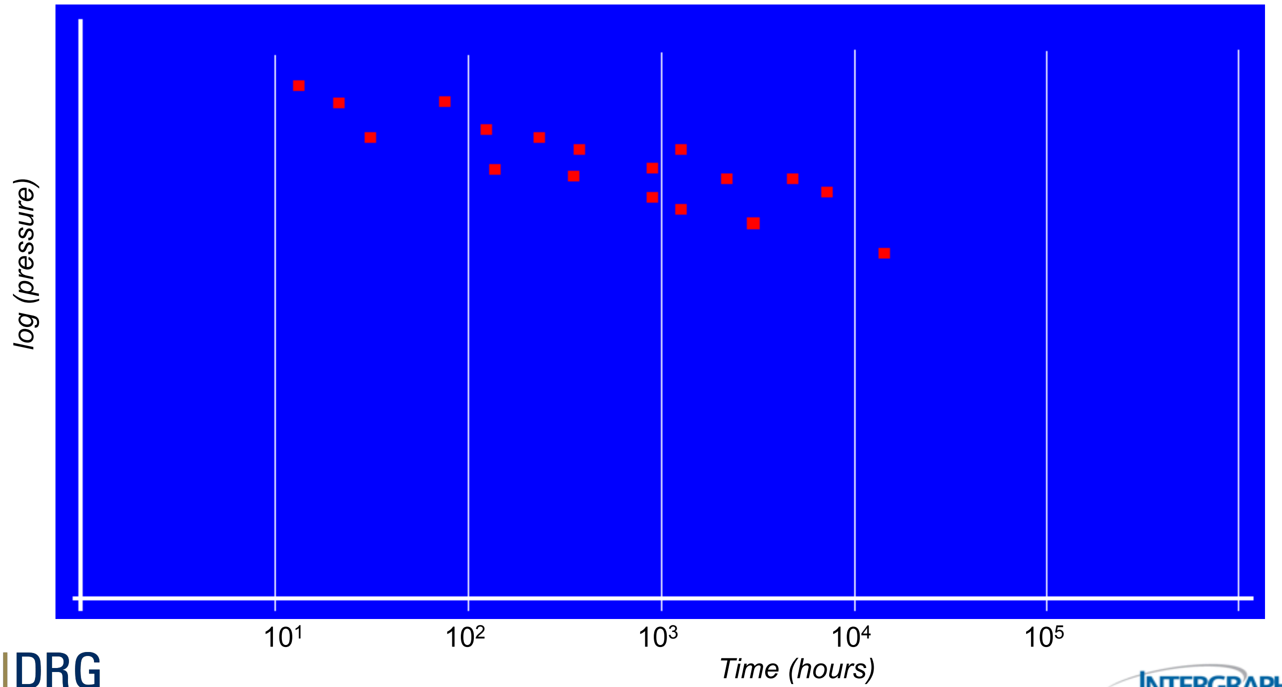

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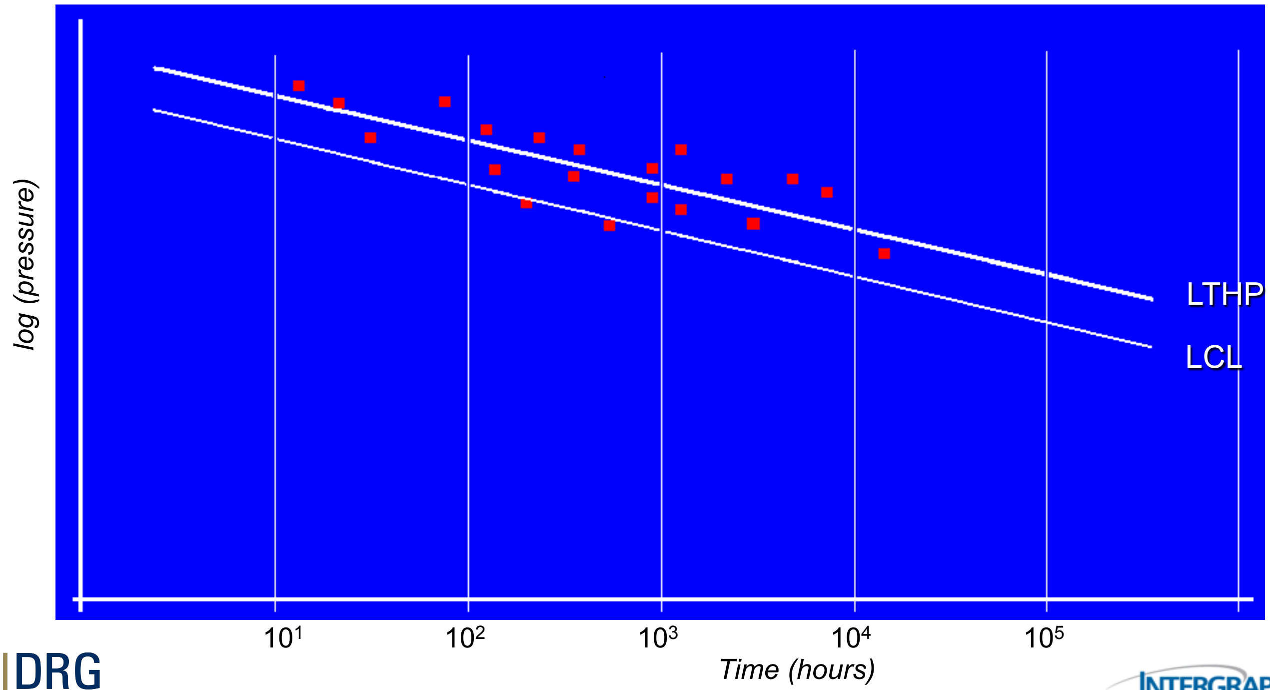

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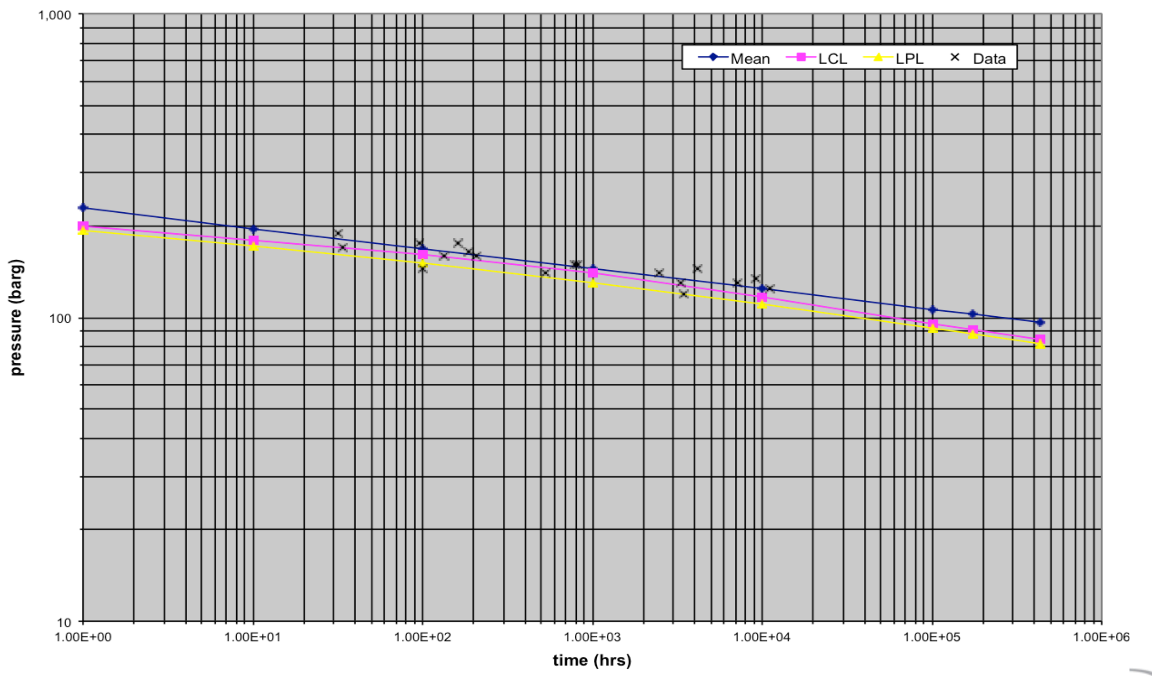
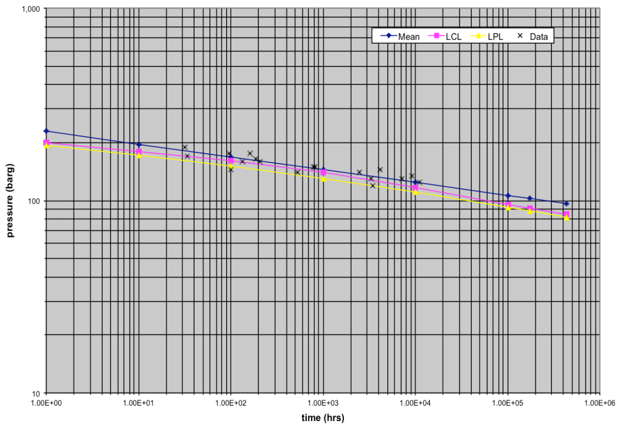
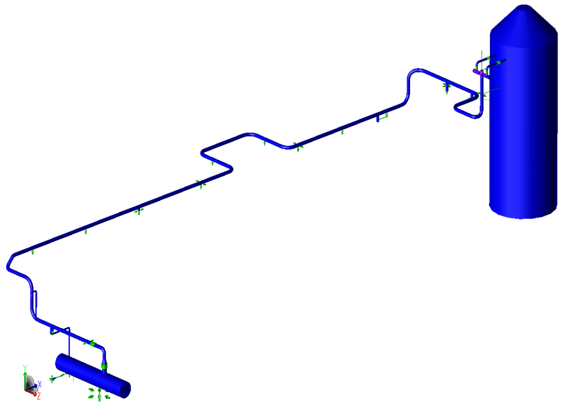


Relation between long-term strength of piping and piping loads

LONG-TERM STRENGTH



PIPING LOADS



GRP-pipe systems often fail due to poor or no engineering

- Axial or hoop
  - Hoop (5%) (Pipe system geometry is simple in circumferential direction)
  - Axial (95%) (Pipe system geometry is complex in axial direction)
- When
  - Small part (<5%) of the failures occurs during installation or operation
  - Most of the failures occur during hydro-testing (pressure testing)
- Where
  - Joints (89%)
  - Fittings (10%)
  - Plane pipe (1%)
- Why
  - Due to material defects (<2%)
  - Defective installation (49%)
  - Overloading of material due to shortcomings in design (49%)

Axially Overloaded pipe failure

Also small bore can cause a lot of collateral damage

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Axial tensile failure at reducer

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Typical failures adjacent to bend

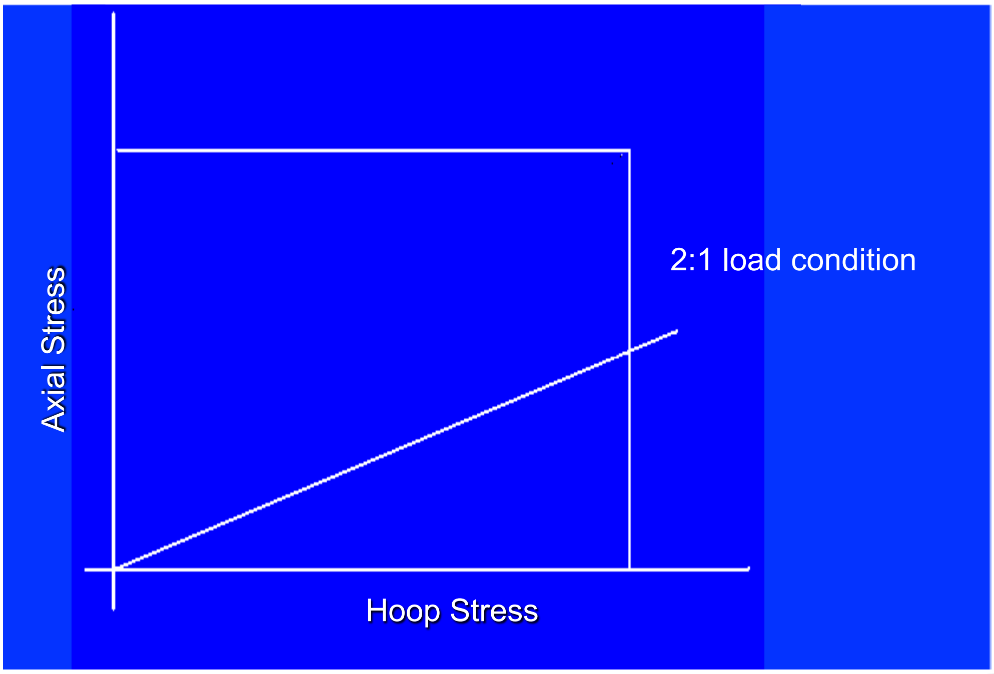
Failure in Pipe Adjacent to bend not in bend

Large tee failure during pressure testing

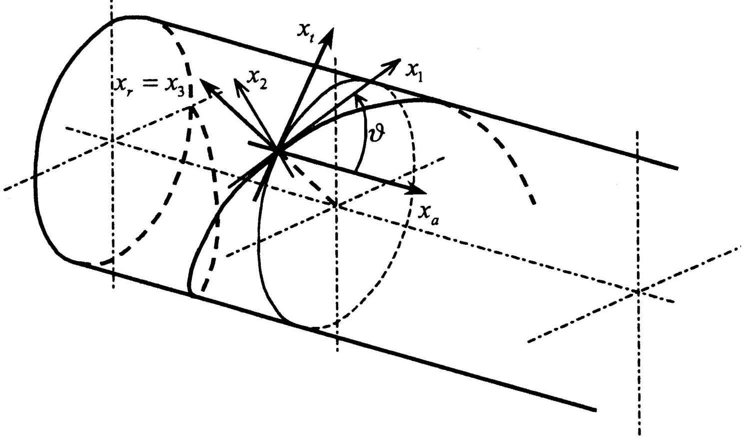
Axially Overloaded joint failure

With large consequential damage due to waterhammer

Construct a design envelope to assess pipe stresses against



Effect of winding angle (netting theory)

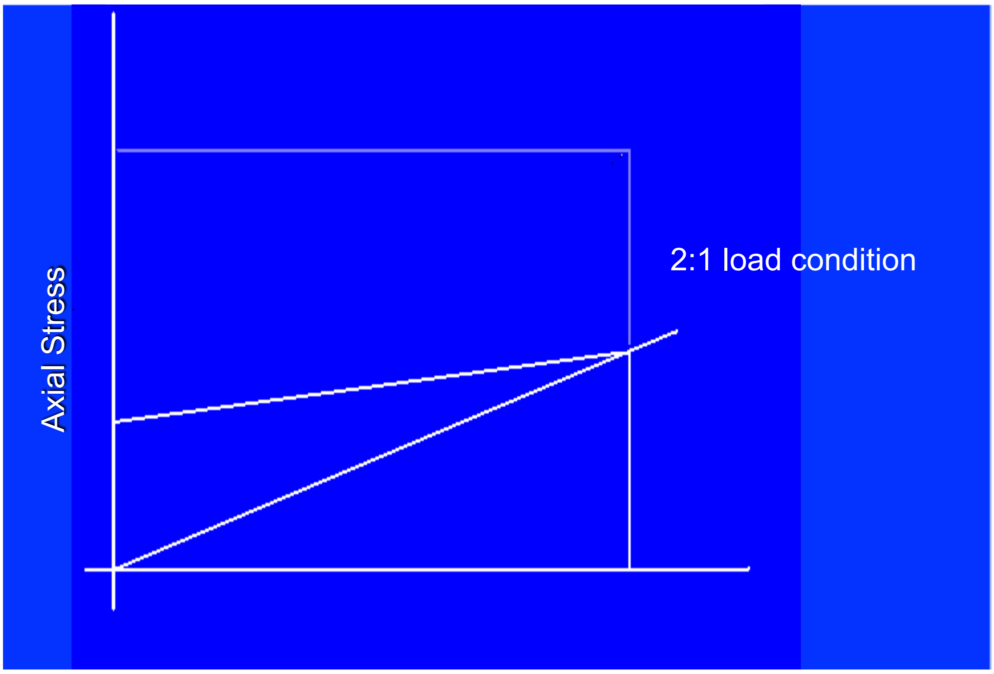


$\Theta = 55°$: $\sigma_{hoop}:\sigma_{axial} = 2:1$

$\Theta = 63°$: $\sigma_{hoop}:\sigma_{axial} = 4:1$

$\Theta = 73°$: $\sigma_{hoop}:\sigma_{axial} = 10:1$

Construct a design envelope to assess pipe stresses against



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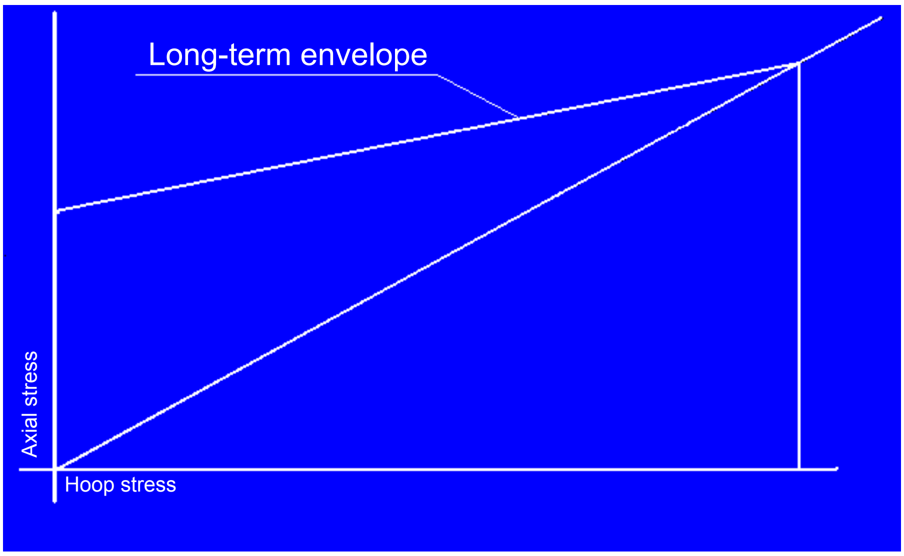

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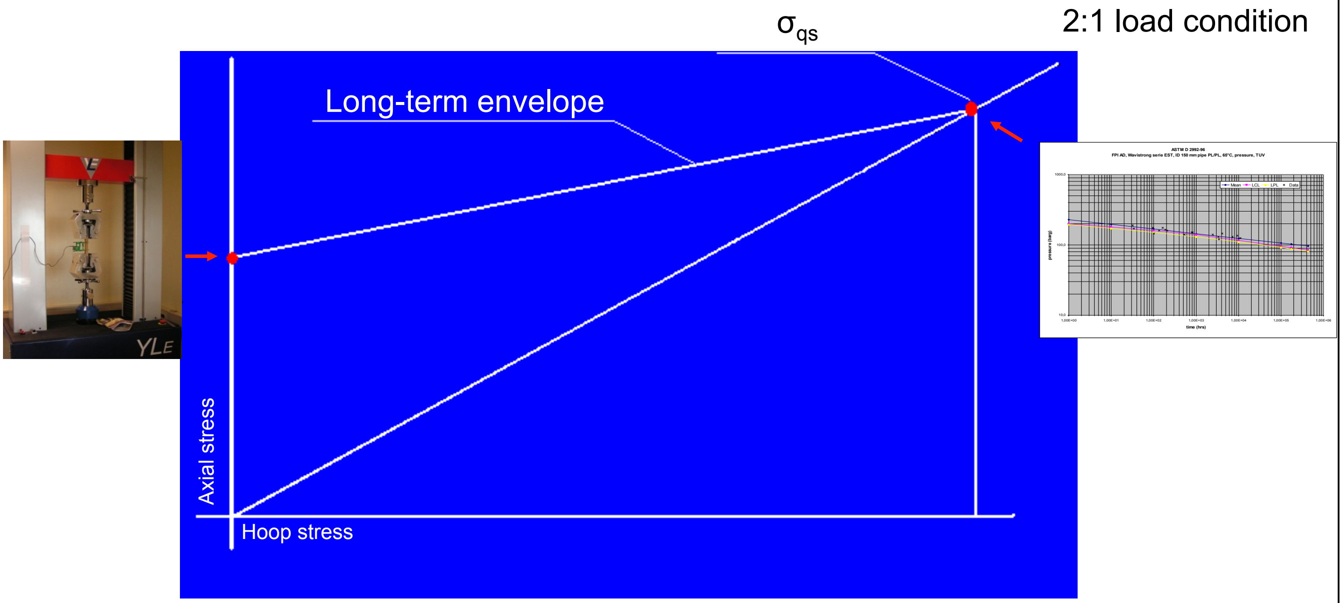

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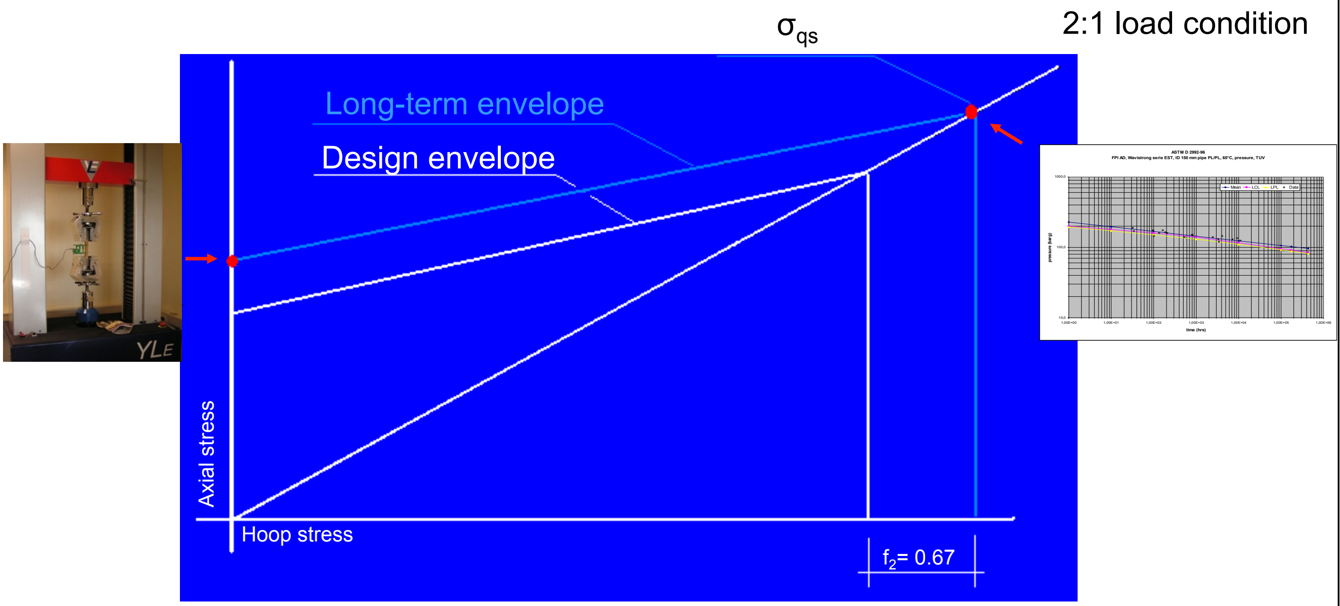


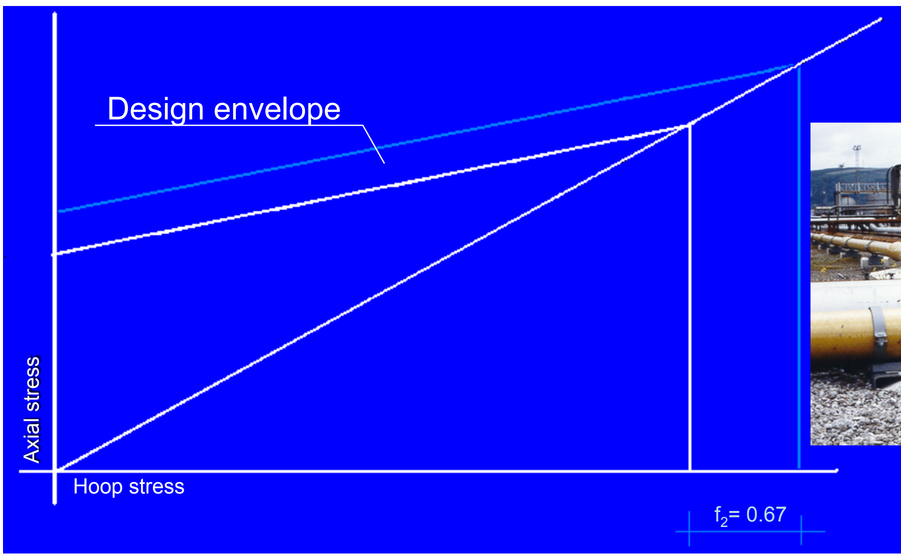
Several f2 safety factor values to create different design envelopes

Table 3 — Default values for f_2

Loading type	Load duration	f_2	Example of loading type
Occasional	Short-term	0,89	Hydrotest
Sustained including thermal loads	Long-term	0,83	Self-mass plus thermal expansion
Sustained excluding thermal loads	Long- term	0,67	Self-mass

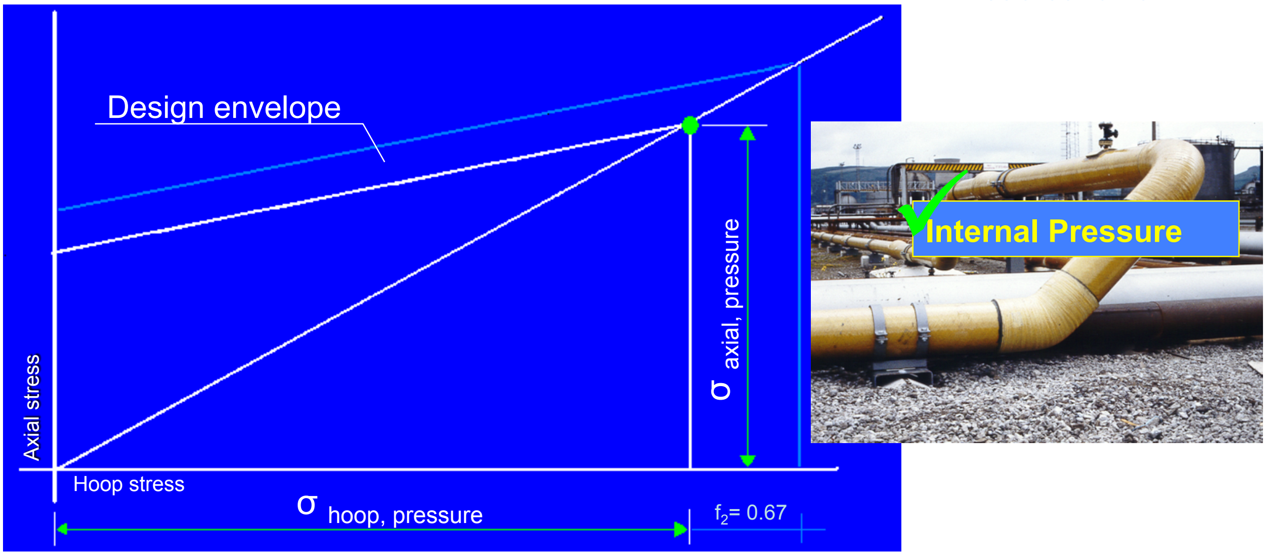
Construct a design envelope to assess pipe stresses against

2:1 load condition



Construct a design envelope to assess pipe stresses against

2:1 load condition



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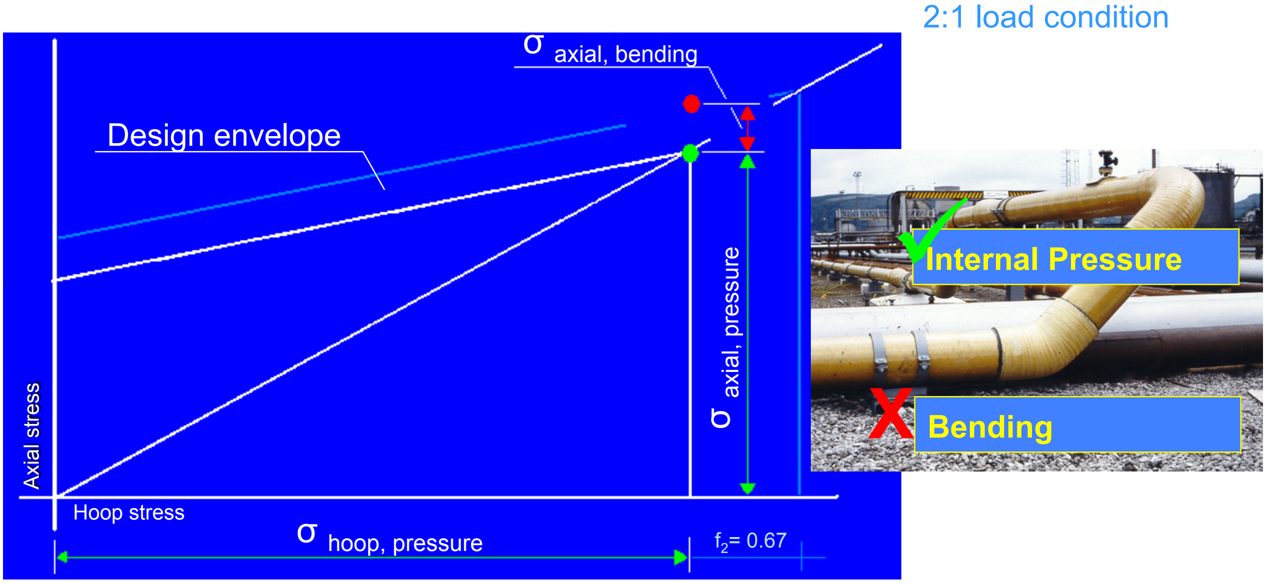

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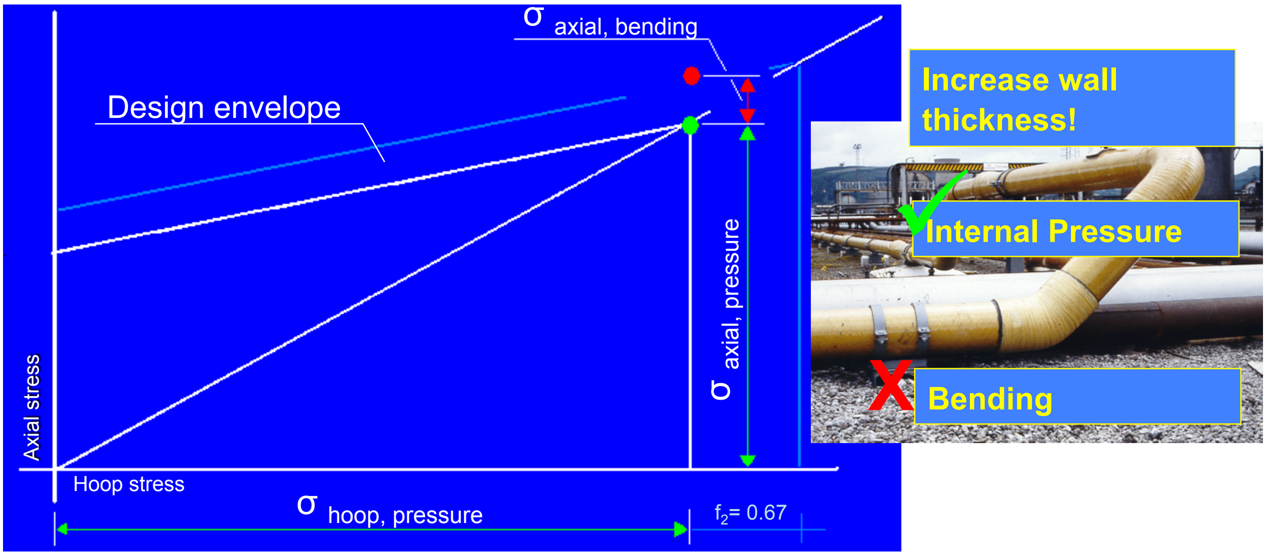

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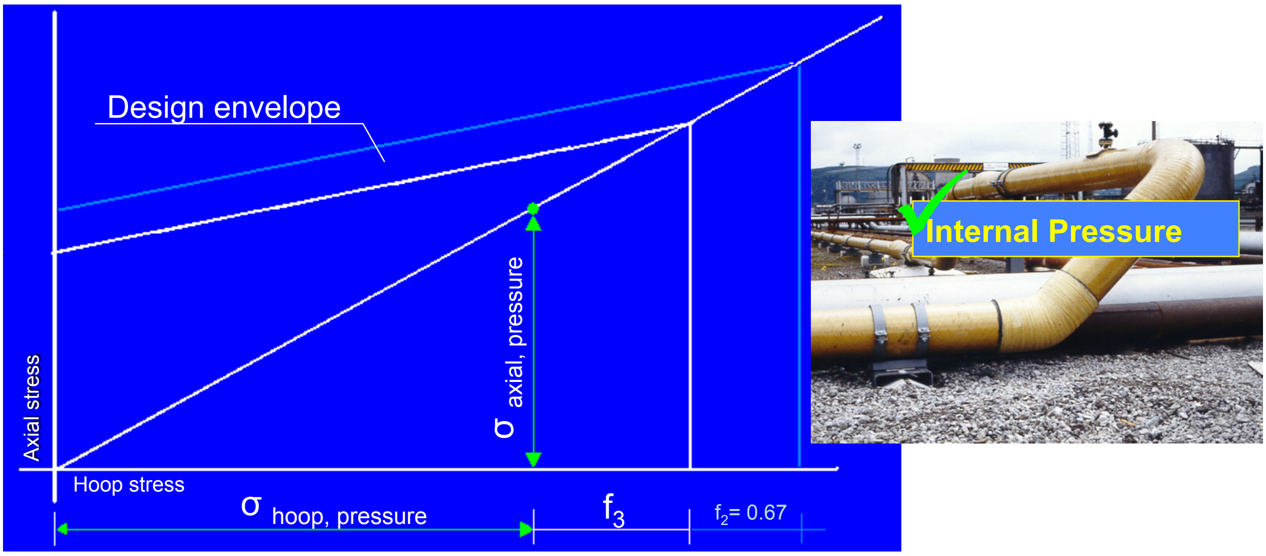
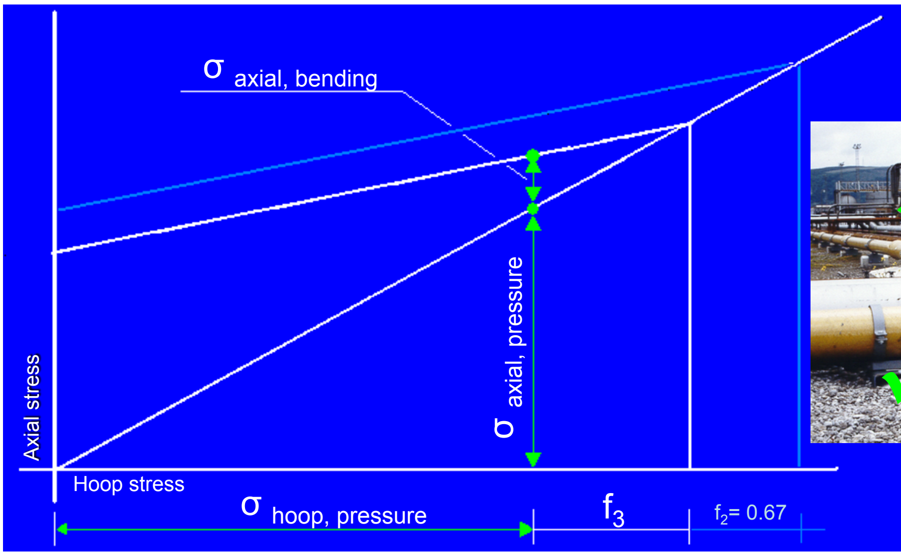
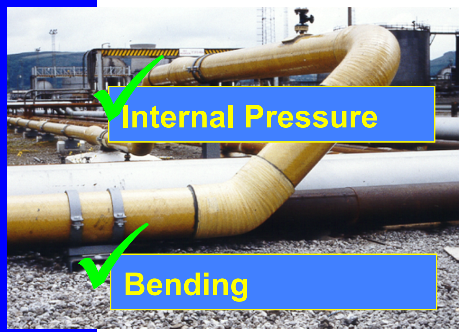


Construct a design envelope to assess pipe stresses against

2:1 load condition





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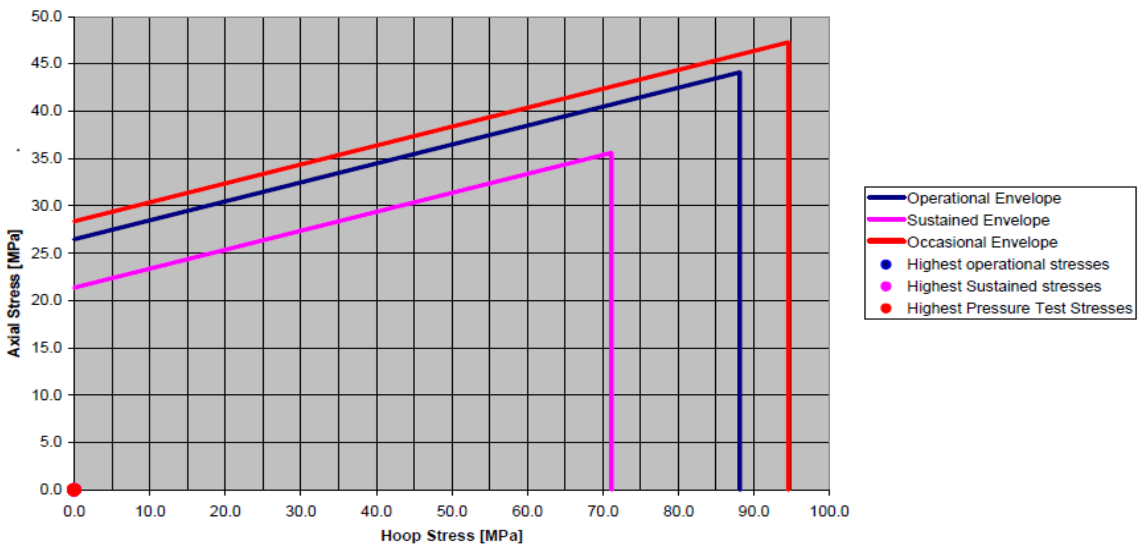
Result: ISO 14692 design envelop that is producer and pipe specific



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Agenda

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- **Using C2**

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Configuration Options C2 for FRP

Typical values from a supplier:

Ea=12,000MPa

Eh=20,400 MPa EhEa=1.7

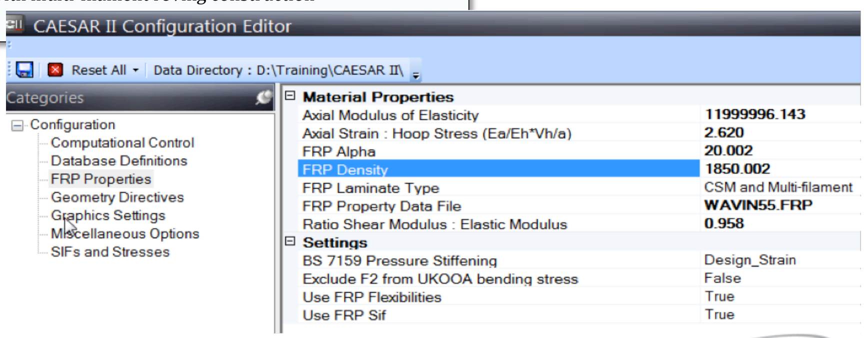
EhEa Vha=0.38 (Poisson Ratio)

Density=1849 kg/m3

CTE=206×10-6 mmmm°C (thermal expansion)

Shear Modulus=11,496 MPa

Bend Laminate Type=Chopped Strand mat with multi-filament roving construction



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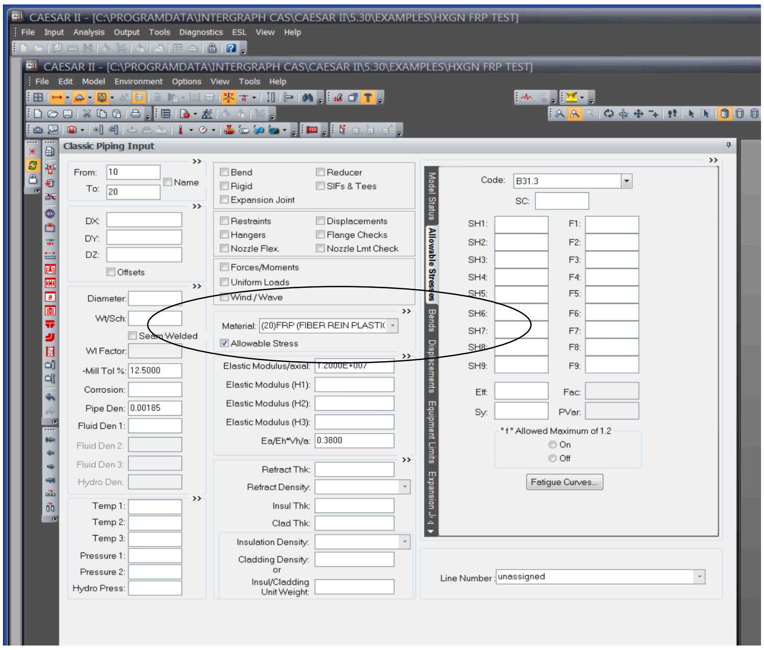
Select FRP material while building your model



Activates Orthotropic material model of C2

Requires several parameters for axial and hoop direction

- Elastic Modulus
- Poisson Ratio
- Shear modulus

Be careful with diameters and wallthicknesses

Use Fitting data from supplier to ensure the right laminate thickness is entered everywhere

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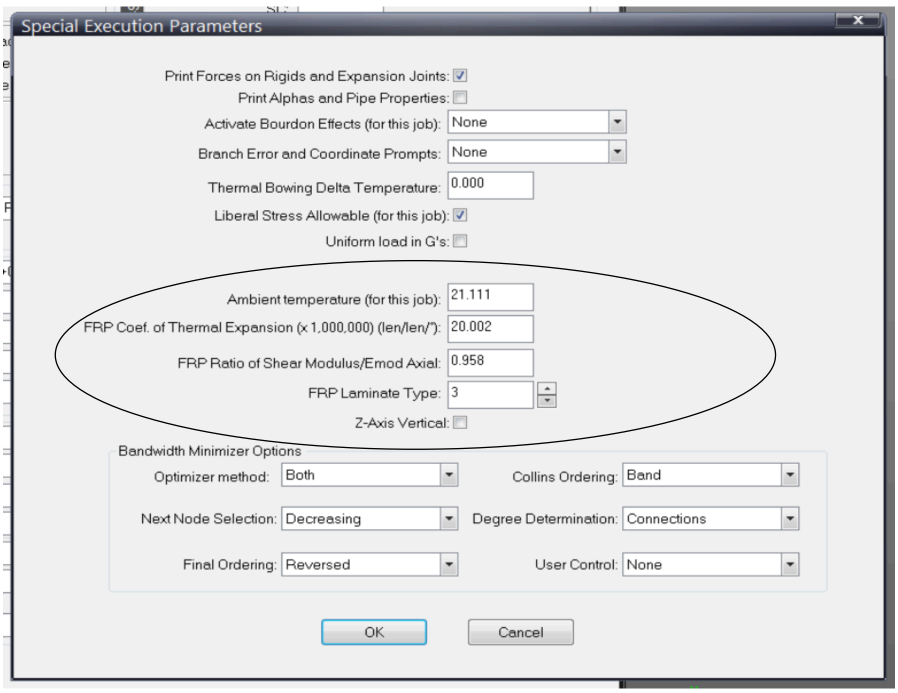
Check the special execution parameters



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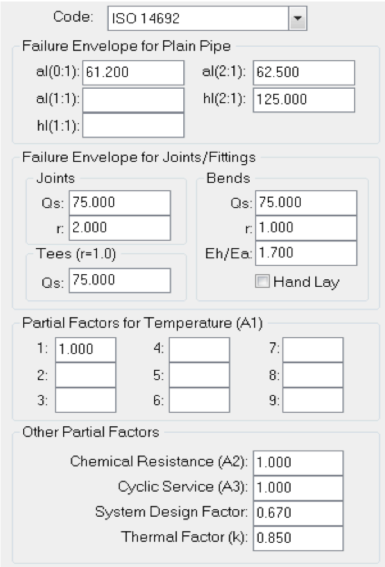
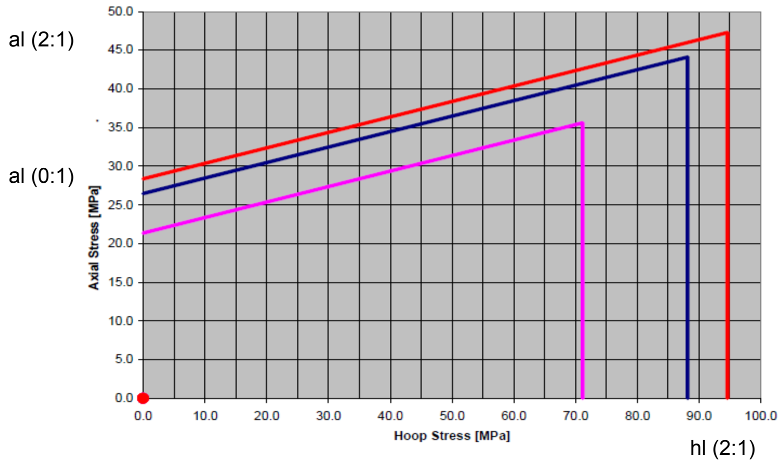
Setting up the Design Envelope using values provided by supplier





Run and evaluate the results is similar to steel except the stresses are evaluated per direction

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