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Centre for Future Materials

Composites repair

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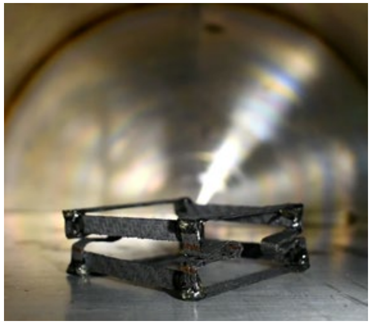
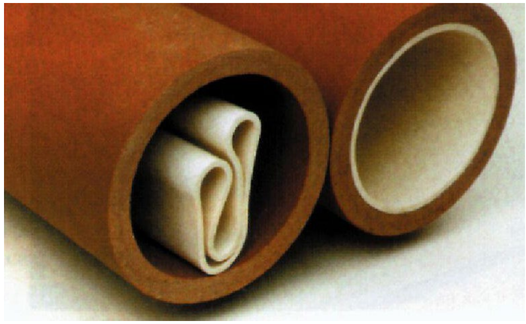
Advanced materials for internal repair of steel pipes

Braided shape-memory polymer composite liner:

Tri-axial braiding machine

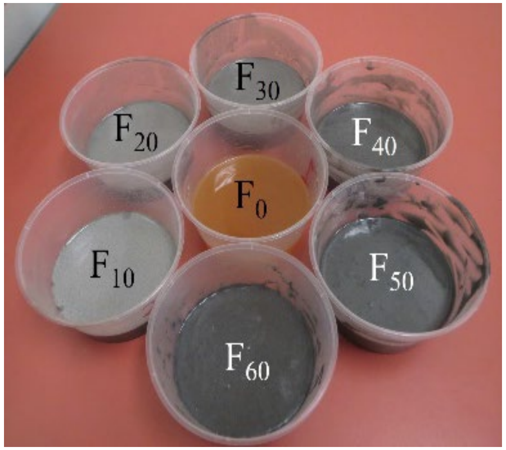


CFR-SMP Structure

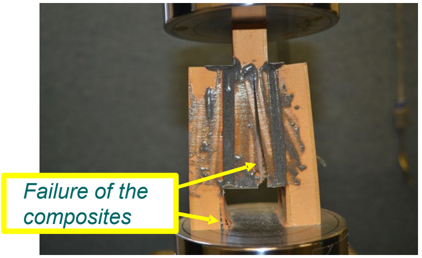


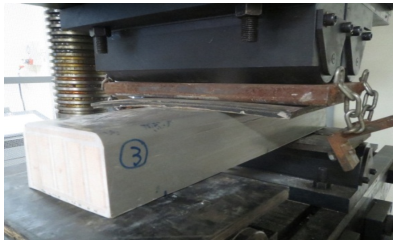
Fold and formed trenchless system (Bruce et al., 2006)

Novel particulate-filled (PF) polymer coating systems:



PF polymer coating





PF coated composite sleepers

Can be engineered to:

- Adhere to steel pipe surfaces with no surface preparation
- Optimal viscosity to ensure penetration but will flow from top of pipe to bottom prior to curing
- Minimal curing requirements
- Compatible with future maintenance and pipeline modifications
- Optimal strength and high durability

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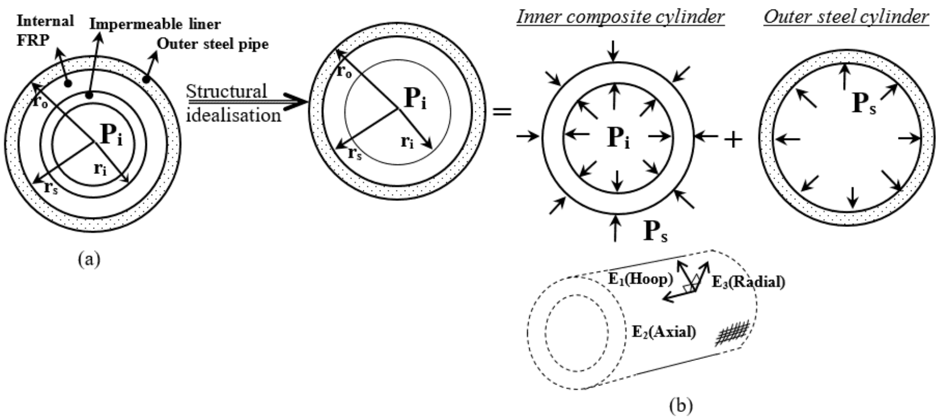
Modelling of composite pipe-in-steel pipes

Analysis of steel pipe with internal composite repair



(a) Internal composite repair components and (b) superposition approach

Pipe geometrical properties						
Type of pipe		150ND				
Outside diameter (mm)		168.3				
Original pipe thickness (mm)		7.11				
Internal corrosion	(LOC) %	0	20	40	60	80
	Internal radius (mm)	77.040	78.462	79.884	81.306	82.728
	External radius (mm)	84.15				
External corrosion	(LOC) %	0	20	40	60	80
	Internal radius (mm)	77.04				
	External radius (mm)	84.150	82.728	81.306	79.884	78.462

Steel material properties		
Type of Steel	X42*	X65*
Young's Modulus (E) - MPa	200000	200000
Poisson's Ratio	0.29	0.27
Specified Minimum Yield Strength-SMYS (MPa)	290	450
Minimum Tensile Strength (MPa)	415	535
Allowable Strain	0.001	0.002

* Steel properties according to API Specification 5L and ASME B31.4-2002 standards

Material properties	GFRP (E glass/Epoxy (M103/3783))
V_f (Fibre volume ratio)	0.5
$E_1 = E_2$ (MPa)	24500
ν_{12}	0.11
σ_{1t} - Allowable tensile strength in longitudinal direction (MPa)	433
σ_{1c}- Allowable compressive strength in longitudinal direction (MPa)	377
Ultimate tensile strain (ε^{u}_{1t})	0.017

$$\begin{matrix}\sigma_{\theta outer} \\ \sigma_{r outer}\end{matrix} = \left\{\frac{(P_s r_s^2 - P_i r_i^2)}{(r_i^2 - r_s^2)}\right\} \pm \left\{\frac{[(P_s - P_i) r_s^2 r_i^2]}{(r_i^2 - r_s^2)}\right\} \frac{1}{r^2}$$

At inner composite cylinder

$$P_s = \frac{\frac{2P_i r_i^2 (1 - r_i^2)}{(r_i^2 - r_s^2)}}{\left[\frac{(r_s^2 + r_i^2)(1 - \vartheta_i^2)}{(r_i^2 - r_s^2)}\right] + [\vartheta_i (1 + \vartheta_i)] + \left[\frac{E_i (1 - \vartheta_o^2)(r_s^2 + r_i^2)}{\mu E_o (r_s^2 - r_o^2)}\right] - \left[\frac{E_i (1 + \vartheta_o)\vartheta_o}{E_o}\right]}$$

Contact pressure at the internal composite repair and steel pipe interface

$$\begin{matrix}\sigma_{\theta outer} \\ \sigma_{r outer}\end{matrix} = \left\{\frac{P_s r_s^2}{(r_o^2 - r_s^2)}\right\} \pm \left\{\frac{P_s r_s^2 r_o^2}{(r_o^2 - r_s^2)}\right\} \frac{1}{r^2}$$

At outer composite cylinder

$$\left(\frac{\sigma_1}{\sigma_{1,\beta}}\right)^2 - \left(\frac{\sigma_1}{\sigma_{1,\beta}}\right)\left(\frac{\sigma_2}{\sigma_{2,\beta}}\right) + \left(\frac{\sigma_2}{\sigma_{2,\beta}}\right)^2 + \left(\frac{\sigma_{12}}{\tau_{12}}\right)^2 = FI$$

Failure index for inner and outer cylinder subjected to internal pressure Pi

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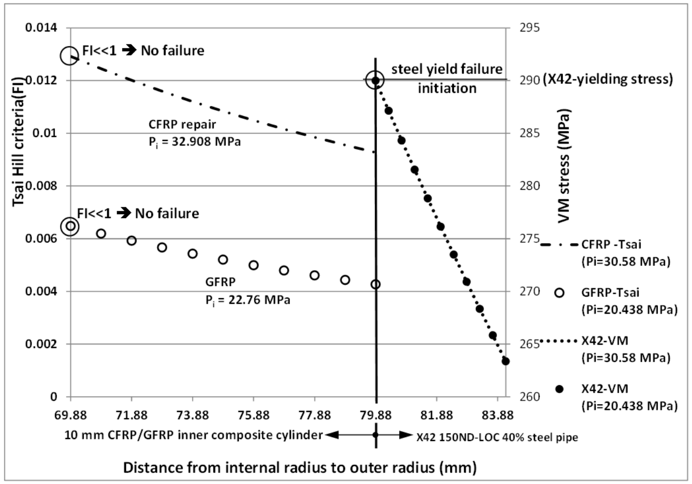
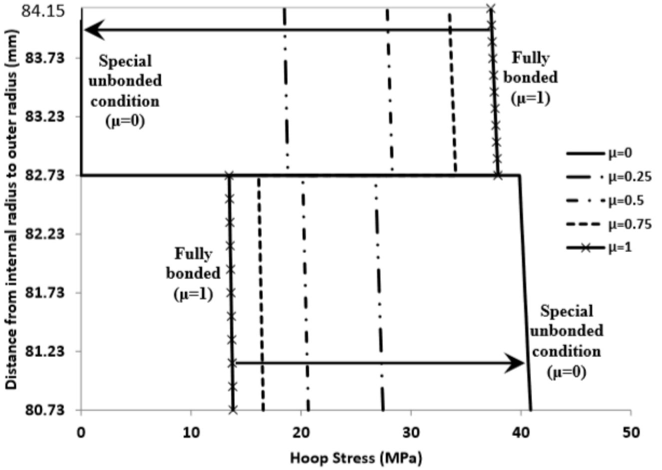
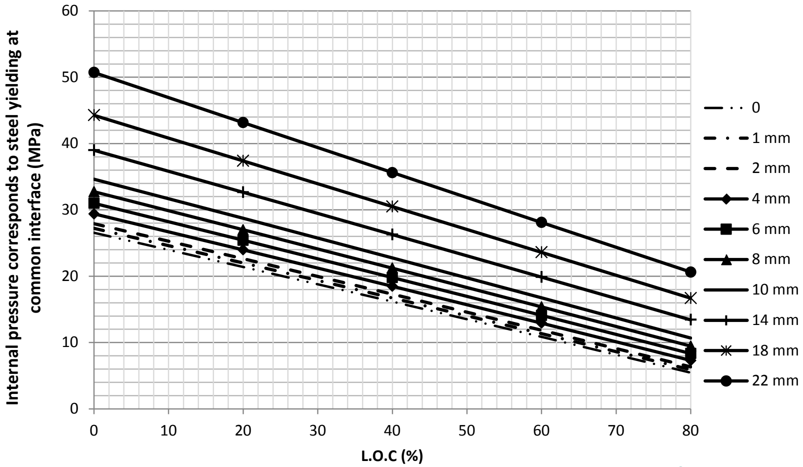


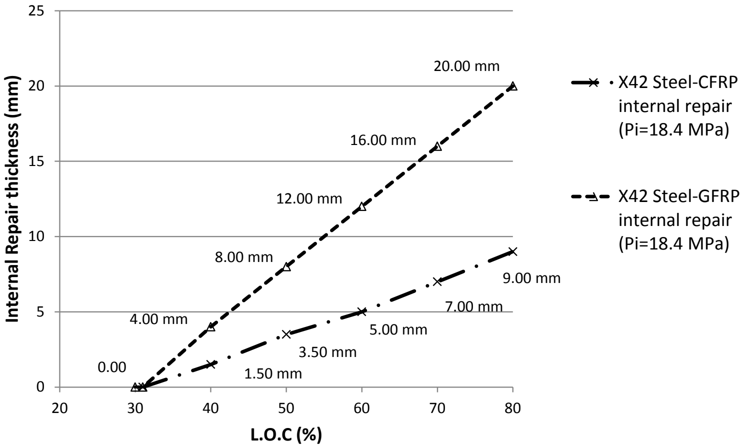
VM stress and Tsai Hill FI variation for 10 mm GFRP and CFRP internal composite repair systems



Through thickness stress variation (hoop direction) against different bond coefficient (X42 150ND - 80% LOC, 2 mm CFRP internal repair, Pi =1MPa)



Internal composite repair design nomographs for 150ND pipe



Required internal composite repair thicknesses for rectify operating pressure of 18.5 MPa for X42 steel

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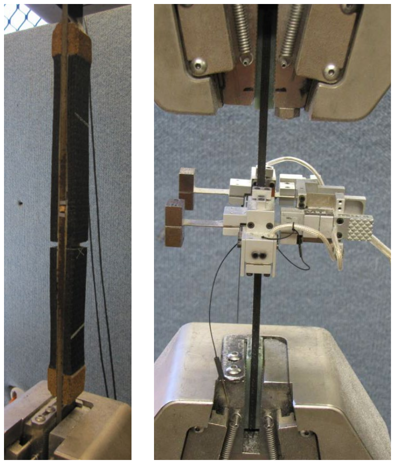
Methods for testing and analysis of repaired steel pipes



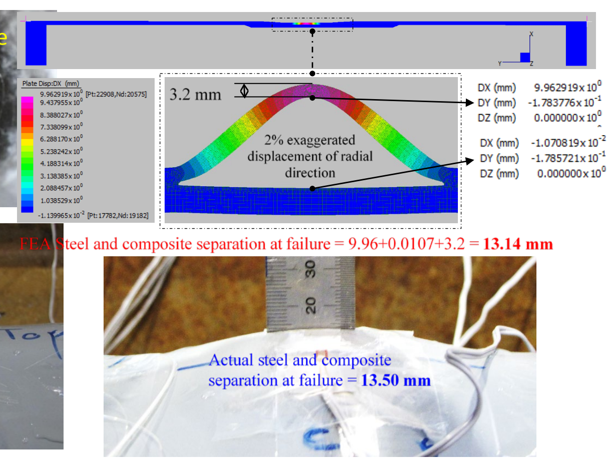
Material characterisation

Impact rig

500 kN fatigue rig

Environmental chamber

Hydrostatic testing of repaired pipes (external and internal)



FE analysis and simulation