

Composites repair

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Advanced materials for internal repair of steel pipes

Braided shape-memory polymer composite liner:



Tri-axial braiding machine

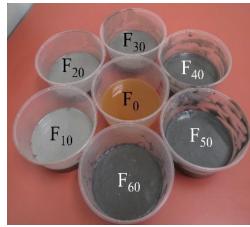


CFR-SMP Structure

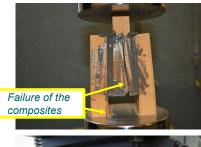


Fold and formed trenchless system (Bruce et al., 2006)

Novel particulate-filled (PF) polymer coating systems:



PF polymer coating





PF coated composite sleepers

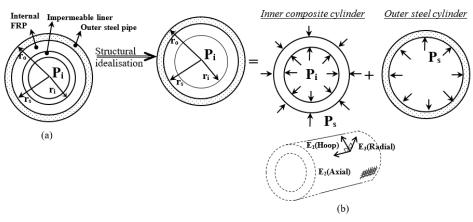
Can be engineered to:

- 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



Modelling of composite pipe-insteel pipes

Analysis of steel pipe with internal composite repair



Pipe geom	etrical p	properti	es			64 - 1 t - '-1		
				Steel material properties				
Type of pipe			150ND			Trung a f Starl	X42*	X65*
neter (mm) 168.3						Type of Steel	X42*	702*
thickness (mm)	7.11					Young's Modulus (E) - MPa	200000	200000
(LOC) %	0	20	40	60	80	Poisson's Ratio	0.29	0.27
Internal radius (mm)	77.040	78.462	79.884	81.306	82.728	Specified Minimum Yield Strength-SMYS (MPa)	290	450
External radius (mm)	84.15					Mariana Tara da Stara ett. (MD-)	415	535
(LOC) %	0	20	40	60	80	Minimum Tensue Strength (MPa)	415	333
External corrosion Internal radius (mm)	77.04					Allowerhle Steering	0.001	0.002
External radius (mm)	84.150	82.728	81.306	79.884	78.462	Allowable Strain	0.001	0.002
	thickness (mm) (LOC) % internal radius (mm) External radius (mm) (LOC) % internal radius (mm) External radius (mm)	thickness (mm) (LOC) % 0 Internal radius (mm) (LOC) % 0 Internal radius (mm) (LOC) % 0 Internal radius (mm) Esternal radius (mm) 84.150	thickness (mm) (LOC) % 0 20 nternal radius (mm) T(LOC) % 0 20 Sternal radius (mm) (LOC) % 0 20 nternal radius (mm) Sternal radius (mm) 82.728	thickness (mm) 7.11 (LOC) % 0 20 40 nternal radius (mm) 77.040 78.462 79.884 External radius (mm) 84.155 50.20 40 (LOC) % 0 20 40 nternal radius (mm) 77.040 78.462 79.884 CLOC) % 0 20 40 nternal radius (mm) 77.04 79.842 External radius (mm) 77.04 70.44	thickness (mm) 7.11 (LOC) % 0 20 40 60 nternal radius (mm) 77.040 78.462 79.884 81.306 Sternal radius (mm) 84.15 (LOC) % 0 20 40 60 Internal radius (mm) 77.04 78.452 79.884 81.306 Sternal radius (mm) 77.04 55.228 81.306 79.884	thickness (nm) 7.11 (LOC) % 0 20 40 60 80 nternal radius (nm) 77.040 78.462 79.884 81.306 82.728 External radius (nm) 84.15 50.00 80.00 80.00 CLOC) % 0 20 40 60 80 nternal radius (nm) 77.04 78.462 98.84 78.462 79.884 81.306 82.728 External radius (nm) 84.150 82.728 81.306 79.884 78.462	7.11 Young's Modulus (E) - MPa (LOC) % 0 20 40 60 80 Poisson's Ratio ntemal radius (mm) 77.040 78.462 79.884 81.306 82.728 Specified Minimum Yield Strength-SMYS Stemal radius (mm) 84.15 Minimum Tensile Strength (MPa) (LOC) % 0 20 40 60 80 internal radius (mm) 77.04 77.04 78.462 Allowable Strength (MPa) Sternal radius (mm) 77.04 78.462 79.884 78.462 Allowable Strain	thickness (mm) 7.11 Young's Modulus (E) - MPa 200000 (LOC) % 0 20 40 60 80 Poisson's Ratio 0.29 internal radius (mm) 77.040 78.462 79.884 81.306 82.728 Specified Minimum Yield Strength-SMYS 290 ixternal radius (mm) 84.15 Minimum Tensile Strength (MPa) 415 (LOC) % 0 20 40 60 80 ntemal radius (mm) 77.04 77.04 Allowable Strain 0.001

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

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

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

$$\begin{split} & \sigma_{\theta_{outer}} \\ & \sigma_{r_{outer}} = \left\{ \frac{(P_s r_s^2 - P_i r_i^2)}{(r_i^2 - r_s^2)} \right\} \pm \left\{ \frac{[(P_s - P_i) r_s^2 r_i^2]}{(r_i^2 - r_s^2)} \right\} \frac{1}{r^2} \\ & P_s = \frac{\frac{2P_i r_i^2 (1 - r_i^2)}{(r_i^2 - r_s^2)}}{\left[\frac{(r_s^2 + r_i^2) (1 - \vartheta_i^2)}{(r_i^2 - r_s^2)} \right] + \left[\vartheta_i (1 + \vartheta_i) \right] + \left[\frac{E_i (1 - \vartheta_o^2) (r_s^2 + r_i^2)}{\mu E_o (r_s^2 - r_o^2)} \right] - \left[\frac{E_i (1 + \vartheta_o) \vartheta_o}{E_o} \right] \\ & \text{At inner composite cylinder} \end{split}$$

Contact pressure at the internal composite repair and steel pipe interface

$$\begin{aligned} &\sigma_{\theta_{outer}} \\ &\sigma_{r_{outer}} = \left\{ \frac{P_s r_s^2}{(r_o^2 - r_s^2)} \right\} \pm \left\{ \frac{P_s r_s^2 r_o^2}{(r_o^2 - r_s^2)} \right\} \frac{1}{r^2} \end{aligned}$$

At outer composite cylinder

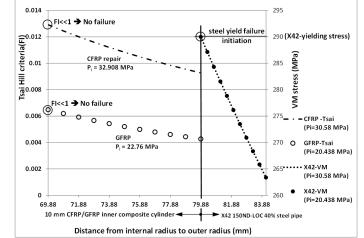
$$\left(\frac{\sigma_1}{\sigma_{1,\beta}}\right)^2 - \left(\frac{\sigma_1}{\sigma_{1,\beta}}\right) \left(\frac{\sigma_2}{\sigma_{2,\beta}}\right) + \left(\frac{\sigma_2}{\sigma_{2,\beta}}\right)^2 + \left(\frac{\sigma_{12}}{\tau_{12}}\right)^2 = FI$$

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

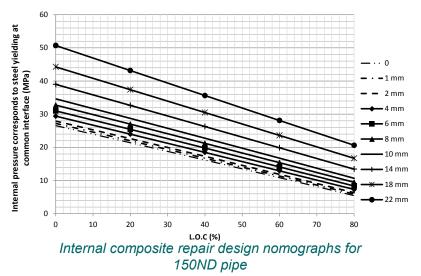


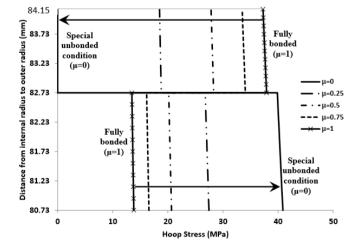
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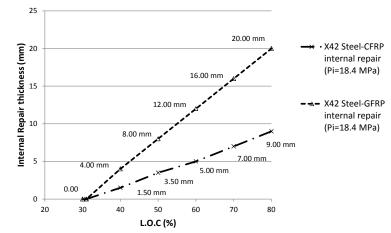


VM stress and Tsai Hill FI variation for 10 mm GFRP and CFRP internal composite repair systems





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



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



Methods for testing and analysis of repaired steel pipes



Material characterisation



Impact rig



500 kN fatigue rig





Hydrostatic testing of repaired pipes (external and internal)

FE analysis and simulation