Using the finite element method for developing a new model predicting the burst pressure of straight defects in corroded pipes repaired with bonded composite wraps

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Abstract:

Introduction/purpose: This work aims to create a novel model that predicts the burst pressure of straight flaws under internal pressure in corroded pipes that have been repaired with bonded composite wraps.

Methods: Geometrical aspects affected the repair performances. The composite patch behaviour strongly depends on several parameters such as pipe size, defect size, composite ply number, ply orientation, composite properties, and adhesive thickness. The effects of all these parameters on the repair efficiency were analyzed.

Results: The obtained results showed that the composite wrap reduces the stress concentration caused by the corrosion defect, which improves the long-term durability of pipes.

Conclusion: The comparison between the new analytically developed model and the finite element (FE) calculations showed good agreement for the repaired corroded pipe.

Keywords: corrosion, uniform pressure, analytical model, pipe, bonded composite repairs

Introduction

Composites are materials of two or more distinct components, offering superior properties to individual materials. However, if a composite has defects, its rigidity decreases (Metehri et al, 2009; 2019; 2024a; Nadia et al, 2024).

Surface flaws are believed to be most common in pipe systems and pressure containers (Mechab et al, 2011; 2014; 2018). A surface fracture is often overlooked during the inspection of a structural component (Mechab et al, 2020). Deterministic approaches are commonly employed in fracture mechanics to evaluate components with suspected or confirmed flaws. These approaches depend on precise hypotheses about the condition of the fault, the material's strength and durability, and the applied force (Fezazi et al, 2021).

Pipe corrosion is a common problem that can lead to leaks and failures. Causes include water or gas quality, temperature, internal pressure, manufacturing defects, etc. Regarding the research method, many researchers have studied the behaviours of composite-repaired corroded pipelines employing field experiments, theoretical deductions, and numerical simulations (Metehri et al, 2024b; 2024c; Alabtah et al, 2021; Kong et al, 2022).

Bonded composite repairs of the structure have become a helpful piping life extension solution over the last two decades (Benyahia et al, 2014; Ibrahim et al, 2018). These repairs provide an efficient method for restoring the ultimate load capability of the structure (Madjdoub et al, 2019). The durability and reliability of structures repaired with composite patches depend mainly on the mechanical and thermal behaviour of the adhesive layer. These are the essential points for studying the causes of failure and the degradation of the entire repair (Lim et al, 2019; Singh et al, 2021).

Glass fibre hoop-reinforced composite systems have proven to be an effective and successful approach for repairing onshore pipelines that have suffered from corrosion and mechanical damage, mainly when the primary stress factor is internal pressure (Chandra Khan et al, 2017). Extending these repair methods to offshore pipelines, such as risers, necessitates a comprehensive understanding of intricate combined load profiles, including substantial tension overlay (De Barros et al, 2018).

Repair methods utilizing glass fiber reinforced materials are employed to restore corroded or damaged pipelines. In this approach, the affected section is strengthened by applying a composite wrap, typically made of glass/epoxy or carbon/epoxy, around the transmission pipelines (Da

Costa-Mattos et al, 2009; Budhe et al, 2017; Alexander et al, 2014). The ability of these Glass fibre-reinforced materials to resist corrosion, their relatively high strength-to-weight ratio, load-bearing capacity, and stiffness makes them an excellent choice for rehabilitating corroded steel pipelines and other mechanical structures. The composite overwrap can ensure an optimal level of pressure-bearing capacity and structural integrity in cases of partial corrosion or partial wall loss defects. However, they may be less effective in preventing leaks in localized through-thickness corrosion defects (Budhe et al, 2020).

Few models in the literature forecast burst pressure in repaired pipes, so we conducted this study to create an analytical model that makes this prediction possible and aids in composite wrap repair design. A finite element analysis presented in this work also describes the impacts of different parameters influencing the repair performances of corroded pipes. The constructed analytical model included each of these parameters.

Geometrical model

In this study, it is supposed that there exists a corrosion defect of a rectangular shape in the central outer wall of a pipeline. The dimensions of the defect are: length (L=300 mm), width (l=200 mm) and defect ratio of the defect depth on the pipe thickness (r=d/t =0.1, 0.2, 0.3, 0.4 and 0.5 mm). The outside diameter of the pipe Dext is 600 mm, Dint represents the inside diameter (Dint = 580 mm), and "t" designates the pipe thickness (t = 10mm); the length of the pipe is 2500mm. The pipeline is subjected to an internal uniform pressure of P=8.42 MPa. Figure 1 illustrates the geometric characteristics of the pipe.

The pipe is made of APC X65 steel, and the corrosion defect is repaired using a glass/epoxy composite wrap with two layers of 0.5 mm thickness for each layer. The ply orientation in the composite is [55/-55]. The composite wrap is bidirectional. We chose to adopt the [55/-55] fiber orientations in the wrapping composite, as this configuration promotes better shear stress absorption which can be significant when repairing pipes exposed to internal pressures. These orientations allow the composite to better withstand the pressure forces exerted on the corroded pipe during its operation, which is crucial for ensuring the repair's effectiveness. Furthermore, the [55/-55] orientations provide increased flexibility, enabling them to more easily conform to the shape of the pipe and ensure optimal adhesion to the corroded surface. This is particularly important for preventing delamination or failure of the repair.

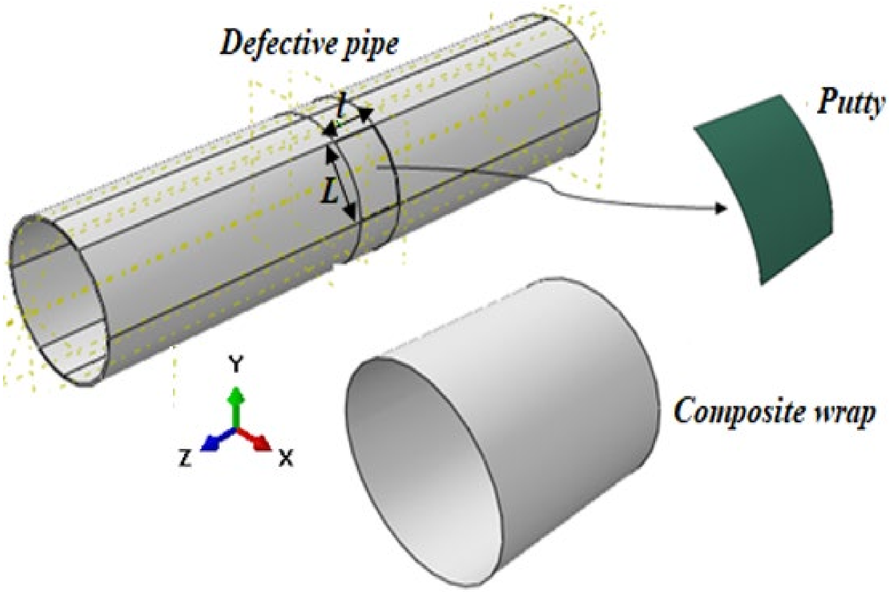

Figure 1 – Corroded pipe repaired with a composite patch wrap and putty

Table 1 – Mechanical properties of different materials used in this study

	Materials				
	Steel X65 (Fatoba & Akid, 2014)	Glass/epoxy (Campilho et al, 2011)	Carbone/ Epoxy (Arroussi et al, 2023)	Araldite 2015 Adhesive (Arroussi et al, 2023)	Putty: Resin Epoxy
E1 (GPa)	211	50	112	1.85	35.9
E2 (GPa)		14.5	8.20		
E3 (GPa)		14.5	8.20		
υ12	0.3	0.33	0.3	0.33	0.389
υ13		0.33	0.3		
υ23		0.33	0.3		
G12 (GPa)		2.56	4.5		
G13 (GPa)		2.56	4.5		
G23 (GPa)		2.24	4.5		
σ_{uits} (MPa)	500				
σ_{e} (MPa)	380				
n	0.127				

The corrosion defect is then cleaned, and a layer of epoxy putty is applied to fill the cavity with a thickness of 0.5 mm. The adhesive used for bonding the pipe to the composite wrap is the Araldite 2015 Epoxy with a thickness of ta= 0.3 mm.

Table 1 shows the elastic properties of the pipe, the patch, and the adhesive. Pipe steel is supposed to have an elastic-plastic behaviour.

Initial conditions and limitations

The extremities of the pipe were constrained (all displacements and rotations were blocked), i.e., U1 = U2 = U3 = 0, UR1 = UR2 = UR3 = 0) to ensure the proper execution of the calculation. Furthermore, the length of the section was chosen so that this indentation does not affect the stress calculations in the corroded and repaired areas. The pipe is subjected to a constant internal pressure of 8.42 MPa, applied uniformly, without considering other real-world specific effects. (The boundary conditions are presented in Figure 2).

In Abaqus software, the contact between the three components in an assembly (pipe, putty, and composite wrap) can be defined by assigning suitable interaction properties (normal and tangential) to the surface-to-surface contacts.

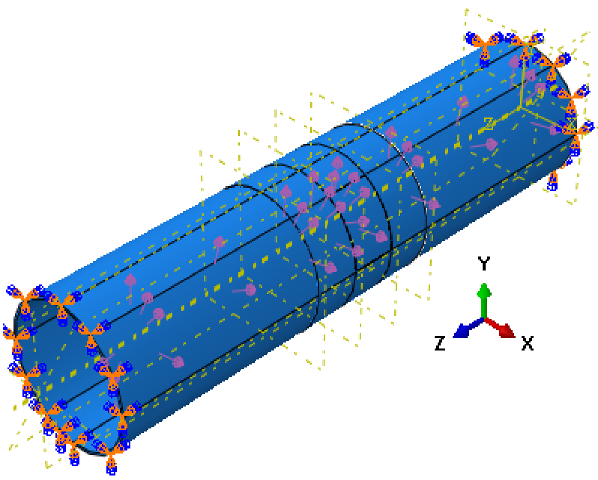

Figure 2 – Boundary condition of the corroded pipe

FEM model and convergence analysis

The Abaqus calculation code (Dassault Systems, The 3D EXPERIENCE platform, 2014) was used to calculate the stresses in the corroded and repaired pipe. The finite element model was divided into three subsections: the repaired pipe, the epoxy putty, and the composite wrap. The pipe is modelled with different elements along the thickness direction: one layer for the pipe, one layer for the repair putty, and two layers for the composite wrap.

Changing the density of the mesh elements stabilized the equivalent stress value in the repaired pipe (see Figure 3).

Table 2 – Numbers of the nodes and the mesh elements

Model	Number of nodes	Number of elements
Pipe with a rectangular defect	61248	40475
Repaired pipe with a composite patch wrap	67030	45788

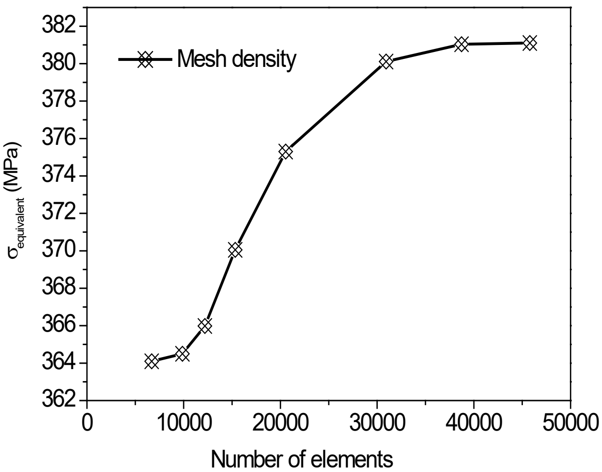

Figure 3 – Variation of von Mises stress in the corroded pipe repaired with composite material as a function of mesh density

Several computational runs with mesh density optimization were used to obtain reliable results and good convergence (see Figure 3). To assess the impact of the number of nodes on stress variation, the type of structural hexahedral linear element was fixed, and an attempt was made to increase the number of nodes to refine the model progressively. Figure 3 illustrates the mesh of the repaired pipe based on the number of nodes.

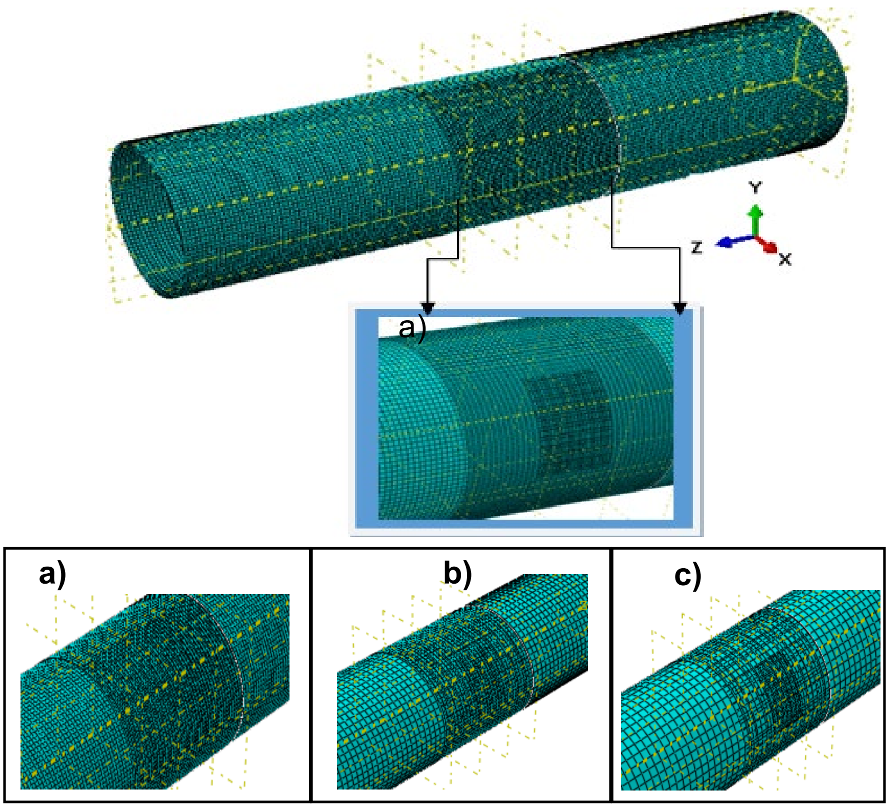

Figure 4 – Detailed mesh used for a numerical model of the defective pipe with composite repair: a) refined mesh, b) medium mesh, and c) non-refined mesh.

The type of element chosen must correspond to the topological shape of the model structure. The element types depend on the three-dimensional shapes, such as tetrahedra, wedges, and hexahedra.

In previous studies (Medjdoub et al, 2018) on the behaviour of repaired pipelines, C3D8R mesh elements were tested and they provided reliable results.

However, the element type was not altered in this work, as the C3D8R element is the most efficient in most numerical analyses; therefore, this element type was selected at the outset of the analysis.

In terms of the mesh type, we opted for the elements (C3D8R) which have been frequently used in the modelling of such structures, along with

5040 linear quadrilateral elements of type S4R for the envelope and 40748 linear hexahedral elements of type C3D8R for the pipe and the putty. Refining the mesh at a defect level is also important to better determine the value of the equivalent and circumferential stresses. The general configuration is based on a regular mesh, which is kept constant for all the analyses carried out in this study to avoid any influence of the mesh on the results. The total number of the nodes and the pipe elements is demonstrated in Table 2. Figure 4 illustrates the structure of the mesh employed for this calculation.

The mesh models shown in Figures 4a, b, and c were generated by adjusting the element density for each material until a mesh size was achieved. This ensured a regular and refined mesh, particularly at the defect level, where corrosion necessitates a refined mesh with a minimum element size.

Finite element results

Comparison between repaired and non-repaired pipes

A comparative study analyzed the stress distribution between an unrepaired corroded pipe and a corroded pipe repaired with a glass/epoxy wrap consisting of two composite layers [55/-55]. The internal uniform pressure applied was 8.42 MPa. The circumferential stress distributions are shown in Figure 5. This Figure shows that the composite wrap's presence considerably reduces the pipe's equivalent stresses, particularly in the corroded region. The presence of the composite shell increases the lifespan of the corroded pipe.

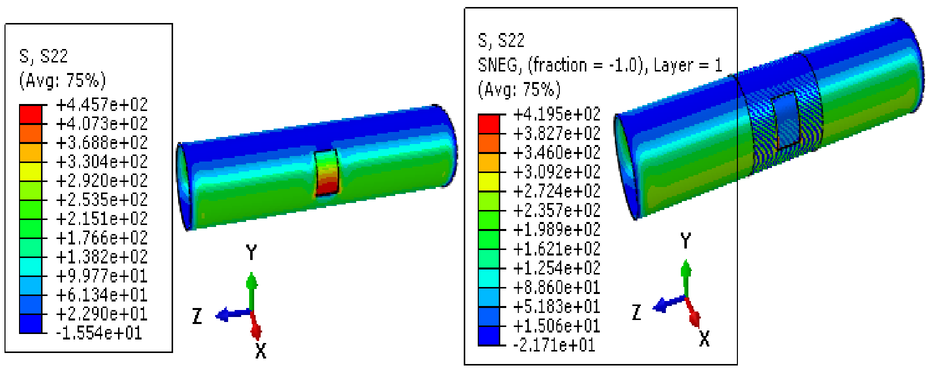

Figure 5 – Contour of circumferential stress with a rectangular centred defect, a) pipe without repaired, b) repaired pipe, under internal pressure. (d/t=0.5)

The stress reduction can be seen more clearly in Figure 6, which shows the maximum stresses for a repaired pipe and an unrepaired pipe as a function of the d/t ratio. From this Figure, it can be seen that the increase in the d/t ratio leads to an increase in the maximum stresses of about 160 MPa from 0.1 to 0.5 for both repaired and unrepaired pipes. However, according to Figure 6, it can be seen that the reduction of the circumferential stress by the composite wrap is constant regardless of the values of the d/t ratio. This means that the rate of stress transfer from the corroded pipe to the composite repair through the adhesive layer is independent of the d/t ratio.

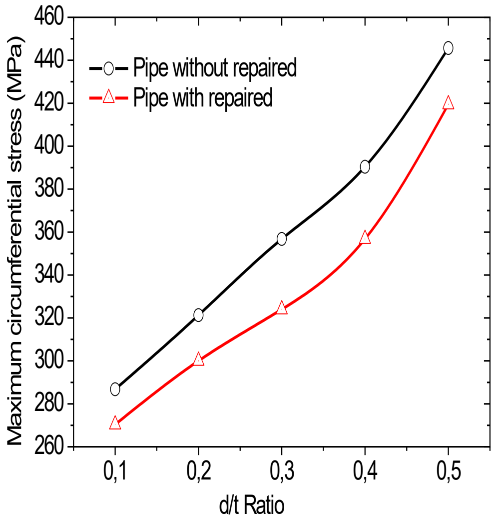

Figure 6 –Variation of the maximum circumferential stress with the repaired pipe and the non- repaired pipe in accordance with the d/t ratio

Effects of the geometrical parameters on the repair performances

Pipe size effect

This part presents the influence of the d/t ratio on the maximum value of the circumferential stress. The study was carried out on a pipe repaired with a composite wrap in glass/epoxy with the ply orientation of [55/-55]; each ply is 0.5 mm thick. The internal uniform pressure of P= 8.42 MPa was applied.

Figure 7 presents the variation of the maximum circumferential stress in the repaired pipe as a function of the d/t ratio for different pipe diameters (400, 500, and 600 mm). From this Figure, it can be noted that the maximum stresses are higher for higher pipe diameters regardless of the d/t ratio. This shows that repair efficiency will be reduced as the pipe diameter increases. This behaviour is due to the fact that the load transfer from the pipe to the composite wrap will be less significant as the pipe diameter increases. It is, therefore, easier to repair a smaller pipe. However, this disadvantage can be overcome by increasing the thickness of the composite by increasing the number of plies, which will result in a higher stress transfer to the composite wrap. Thus, the effectiveness of the repair will be improved.

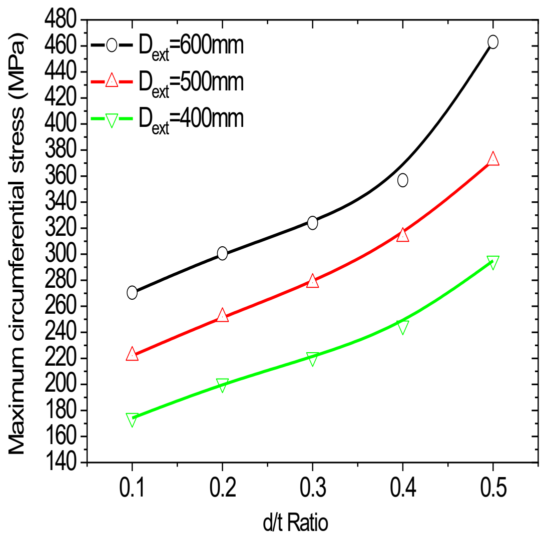

Figure 7 – Variation of the maximum circumferential stress in the repaired pipe as a function of the d/t ratio and the exterior radius

Effect of the defect length

This part of the study focuses on analyzing the effect of defect length on the level of the circumferential stresses in the repaired pipe. For this reason, the defect lengths were L1=500mm, L2=350mm, and L3=110mm. Figure 8 presents the variation of the maximum stress in the repaired pipe as a function of the ratio (d/t) of different defect lengths (L).

This Figure shows that defect length considerably determines the level of circumferential stresses. The repair efficiency is closely related to defect length. For more significant defects, the stress level will be higher and significant even after repair. However, many authors have investigated the effect of defect length (Al-Amin & Zhou, 2013; Hocine et al, 2024; Netto et al, 2007). We can solve this problem by increasing the composite thickness, which will improve the repair effectiveness.

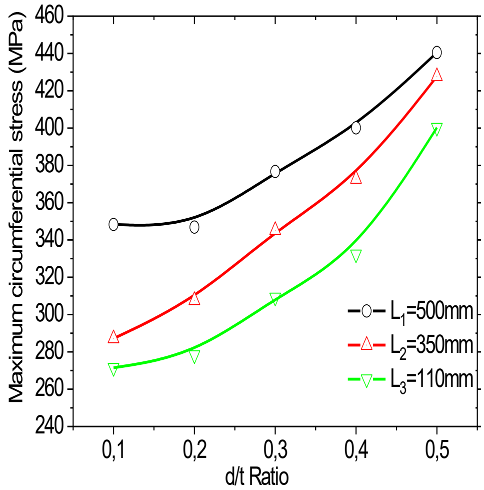

Figure 8 – Variation of the maximum circumferential stress in the repaired pipe as a function of the d/t ratio of different defect lengths

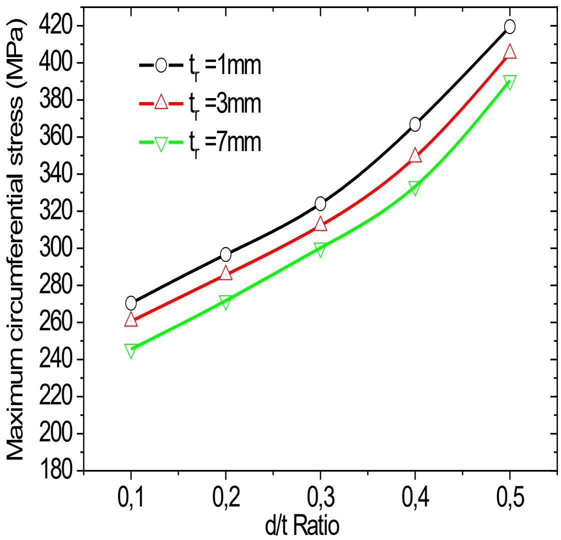

Figure 9 – Maximum circumferential stress variation in accordance with the composite patch thickness

Effect of the composite wrap thickness

To analyze the effects of the composite envelope thickness on the repair effectiveness, we considered three thicknesses of the repair composite: tr =1, 3, and 7 mm (as shown in Figure 9). It can be seen from this last Figure that increasing the thickness of the composite gives a considerable reduction in the maximum stress in the repaired pipe, which allows us to assert that increasing the number of layers of the repair composite improves the repair effectiveness and thus increases the longevity of the pipe. However, we recommend optimizing this thickness to avoid high repair costs, as costly repair may be less cost-effective than replacing the corroded part of the pipe.

Effect of the material properties of the composite wrap

The choice of the composite wrap type is of paramount importance when reinforcing pipelines. Several types of reinforcement are available, the most effective choices being glass/epoxy and carbon/epoxy. These types of composite wraps have demonstrated superior performance by improving mechanical properties.

Table 1 presents the elastic properties of carbon and epoxy compared to those of glass and epoxy.

Figure 10 presents the variation of the maximum circumferential of the repaired corroded pipe with both composites (glass/epoxy and carbon/epoxy). A comparison between the two patches, glass/epoxy and carbon/epoxy, reveals that the glass/epoxy patches offer superior performance in corroded pipeline repair. The stress in the corroded pipe is lower when it is repaired with glass/epoxy than when it is repaired with carbon epoxy, particularly for a lower ratio (d/t). For higher values of the d/t ratio, the two composites give the same circumferential stress. We conclude that the choice of the composite type significantly impacts the repair efficiency. It is recommended for corroded pipes under internal pressure to use glass/epoxy because of its relatively low cost and best efficiency.

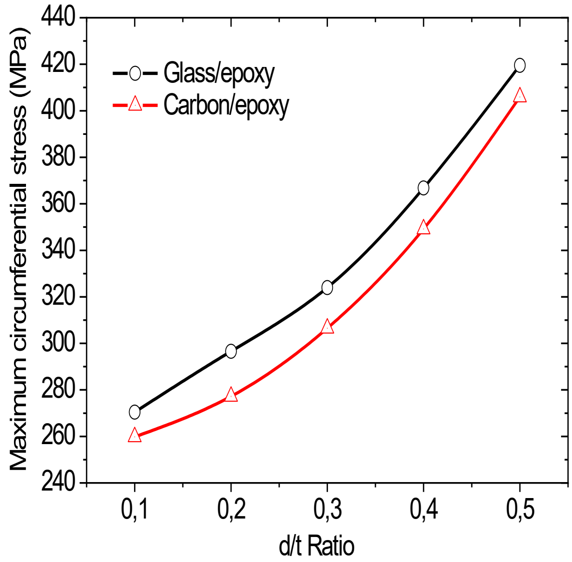

Figure 10 – Variation of the maximum circumferential stress of a repaired pipe in accordance with the composite wrap type

Several studies have been conducted to assess the mechanical properties in order to select the proper material for repairing the damaged cavity of a damaged pipeline (Lim et al, 2019; Da Costa Mattos et al, 2009; Djahida et al, 2021; Zecheru et al, 2018; Duell et al, 2008).

Effect of the adhesive thickness

The adhesive layer plays an important role in the repair of corroded pipes. The thickness and mechanical properties of the adhesive are essential in the load transfer between the corroded pipe and the composite wrap. Figure 11 presents the variation of the repaired pipe's maximum von Mises stress in accordance with the adhesive thickness. From Figure 11, it can be seen that increasing the adhesive thickness leads to a decrease in the equivalent stresses of the corroded pipe. This increase indicates that a moderately thin adhesive (t_a=0.4mm) facilitates better load transfers from the defect to the composite patch. It can be seen that the adhesive thickness influences the equivalent stresses. The minimum value of the equivalent stress is recorded in the interval of (0.3-0.4 mm) for the adhesive thickness; for the adhesive thicknesses higher than 0.4 mm, the stresses increase considerably, and the repair efficiency will be reduced. We recommend using the optimum value of the adhesive thickness (t_a=0.3mm) to repair corroded pipelines.

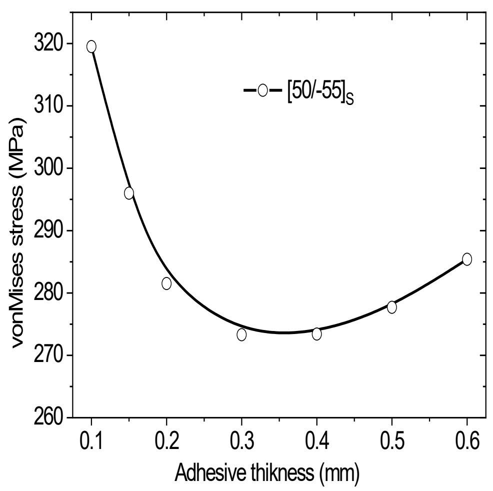

Figure 11 – Variation of the repaired pipe's maximum von Mises stress as a function of the adhesive thickness

Analytical model of the burst pressure of a repaired pipe

Finite element analysis has shown that several parameters influence the burst pressure of a corroded steel pipe repaired with a composite wrap. These parameters include the geometric properties of the pipe, the corrosion defect and the repair composite, the elastic properties of the composite, and the internal pressure applied to the pipe. We have combined all these parameters into an analytical model estimating the burst pressure of the repaired pipe. This model, developed for the first time, can be used to design the composite wrap repair. This model is written in the form:

$$P_b = \frac{2t\,\sigma_{uts}}{(D-t)\,H} \quad .\text{For} \quad 1{,}345 \le \frac{L}{\sqrt{Dt}} \le 6{,}455 \quad ,0.1 \le \frac{d}{t} \le 0.5 \tag{1}$$

$$H = \zeta.\xi.\chi.f\left(\frac{L}{\sqrt{D.t}},\frac{d}{t}\right) \tag{2}$$

$$\zeta = \left(\frac{E_1}{G_{12}}\right).\left(\frac{E_2}{E_3}\right).\left(\frac{G_{13}}{G_{23}}\right) \tag{3}$$

$$\xi = \left(\frac{t}{t_r}\right) \quad (4)$$

$$\chi = \left(\frac{E_a}{E_p}\right) \cdot \left(\frac{\upsilon_a}{\upsilon_p}\right) \quad (5)$$

$$f\left(\frac{L}{\sqrt{D.t}}, \frac{d}{t}\right) = A_0 + A_1\left(\frac{L}{\sqrt{D.t}}\right) + A_2\left(\frac{L}{\sqrt{D.t}}\right)^2 \quad (6)$$

$$A_0 = -13{,}13312\left(\frac{d}{t}\right)^2 + 11{,}17065\left(\frac{d}{t}\right) + 1{,}93764$$
$$A_1 = 5{,}05975\left(\frac{d}{t}\right)^2 - 3{,}2674\left(\frac{d}{t}\right) + 0{,}36372 \quad (7)$$
$$A_2 = -0{,}60838\left(\frac{d}{t}\right)^2 + 0{,}40765\left(\frac{d}{t}\right) - 0{,}0331$$

This model is one of a few ones in the literature to predict the burst pressure of a corroded pipe repaired with a composite wrap. Comparing its results with those obtained by finite element analysis shows an excellent agreement (see Figure 12). Indeed, the relative difference between the burst pressure estimated by the model and that calculated by finite elements does not exceed 0.1 %.

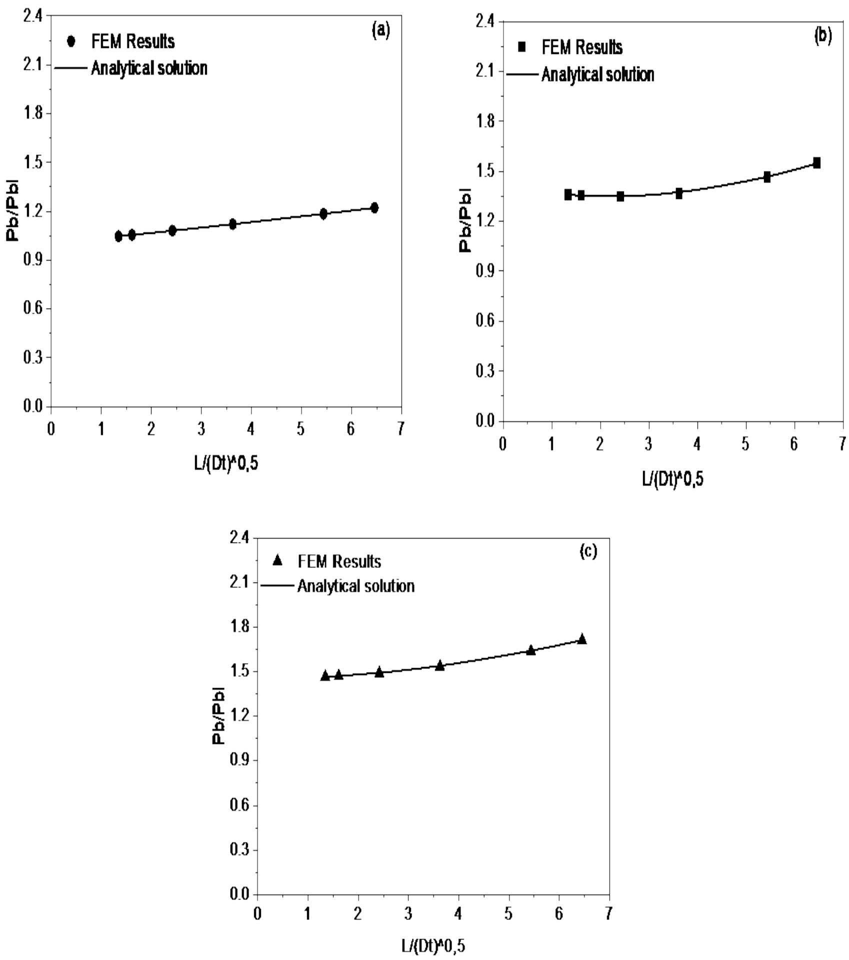

Figure 12 – Burst pressure of the corroded pipe vs L/ (Dt) 0.5

Conclusion

This work develops a new predictive model for calculating the burst pressure of straight defects subjected to internal pressure in corroded pipes that have been repaired with bonded composite coverings. Various criteria are examined, including pipe dimensions, defect size, number of composite plies, ply orientation, composite material characteristics, and adhesive thickness. The following conclusions can be made:

- ✓ The increase in the (d/t) ratio leads to an increase in the maximum stresses for both repaired and unrepaired pipes.

- ✓ As the pipe diameter increases, the load transfer from the pipe to the composite wrap becomes less significant, making repairs easier for smaller pipes. However, this limitation can be mitigated by increasing the composite thickness with additional plies, which improves stress transfer to the composite wrap. As a result, the effectiveness of the repair is enhanced.
- ✓ The defect length plays a crucial role in determining the level of circumferential stresses and directly affects the repair efficiency. For larger defects, stress levels remain high even after the repair. However, increasing the composite thickness helps distribute the stresses more effectively, thereby improving the overall effectiveness of the repair.
- ✓ Increasing the thickness of the composite significantly reduces the maximum stress in the repaired pipe. This demonstrates that adding more layers of the composite improves the repair effectiveness and extends the pipe's service life.
- ✓ Glass/epoxy offers better performance in terms of strength and flexibility, making it more effective in restoring the integrity of damaged pipes. This combination proves to be more advantageous for ensuring durable and reliable repair.
- ✓ It has been determined that the adhesive thickness should be 0.3 mm to ensure optimum adhesion between the composite layer and the thick pipe. This precise value guarantees an effective repair by maintaining a strong and uniform interface between the different layers of the repair system.
- ✓ The present model exhibits excellent agreement with finite element results in predicting the burst pressure of a corroded pipe repaired with a composite wrap, with the relative difference not exceeding 0.1%.

Nomenclature

FEM:	Finite element method
σ_{eq}:	Maximum von-Mises equivalent stress
S_{22}:	Circumferential (Hoop) stress
σ_{uits}:	Ultimate stress
σ_e :	Yield stress
a:	Pipe length
A_0, A_1 and A_2:	Integration functions
d:	Defect depth
Next:	Pipe external diameter

D_{int}:	Pipe internal diameter
E_1 :	Young's modulus in the X direction (GPa)
E_2 :	Young's modulus in the Y direction (GPa)
E_3 :	Young's modulus in the Z direction (GPa)
Ea :	Young's modulus of adhesive
E_P :	Young's modulus of steel
G_{12} :	Shear modulus in the X-Y plan (GPa)
G_{13} :	Shear modulus in the X-Z plan (GPa)
G_{23} :	Shear modulus in the Y-Z plan (GPa)
l :	Defect width
L_1, L_2, L_3 :	Defect length
n:	Work hardening coefficient
LPC:	Line pipe corrosion model
P:	Internal pressure
P_b :	Burst pressure
r=d/t:	Geometrical ratio of the defect
t :	Pipe thickness
Ta:	Adhesive thickness
Tr:	Patch thickness
ζ :	Properties ratio of the composite
η :	Function depending on the ratio of the defect
ν_{12} :	Poisson's ratio in the X-Y plan
ν_{13} :	Poisson's ratio in the X-Z plan
ν_{23} :	Poisson's ratio in the Y-Z plan
ξ:	Thickness ratio
χ :	Properties ratio of steel and adhesive

References

Hocine, A., Achira, F.S.K., Habbar, G., Levent, A., Medjdoub, S.M., Maizia, A., Dhaou, M.H. & Bezazi, A. 2024. Structural integrity assessment of corroded pipelines repaired with composite materials – Literature review. *International Journal of Pressure Vessels and Piping*, 210, p.105253. Available at: https://doi.org/10.1016/J.Ijpvp.2024.105253

Alabtah, F.G., Mahdi, E. & Eliyan, F.F. 2021.The use of fiber reinforced polymeric composites in pipelines: A review. *Composite Structures*, 276, p.114595. Available at: https://doi.org/10.1016/j.compstruct.2021.114595

Al-Amin, M. & Zhou, W. 2013. Evaluating the system reliability of corroding pipelines based on inspection data. *Structure and Infrastructure Engineering*, 10(9), pp.1161–1175. Available at: https://doi.org/10.1080/15732479.2013.793725

Alexander, C., Vyvial, B. & Wilson, F. 2014. Pipeline repair of corrosion and dents: comparing composite repairs and steel sleeves, In: *10th International pipeline conference*, Alberta. Available at: https://doi.org/10.1115/IPC2014-33410

Benyahia F, Albedah A. & Bachir Bouiadjra. B. 2014. Stress Intensity Factor for Repaired Circumferential Cracks in Pipe With Bonded Composite Wrap. *Journal of Pressure Vessel Technology*. 136(4), p.041201. Available at: https://doi.org/10.1115/1.4026022

Budhe, S., Banea, M.D. & de Barros, S. 2020. Analysis of Failure Pressure of Defective Pipes Repaired with Composite Systems Considering the Plastic Deformation of Pipe. *Journal of the Institution of Engineers (India) Series C*, 101, pp.929-936. Available at: https://doi.org/10.1007/s40032-020-00612-4

Budhe, S., Banea, M.D., Rohem, N.R.F., Sampaio, E.M. & de Barros, S. 2017. Failure pressure analysis of composite repair system for wall loss defect of metallic pipelines. *Composite Structure*., 176, pp.1013-1019. Available at: https://doi.org/10.1016/j.compstruct.2017.06.044

Campilho. R.D.S.G., Pinto, A.M.G., Banea, M.D., Silva R.F. & da Silva L.F.M. 2011. Strength Improvement of Adhesively-Bonded Joints Using a Reverse-Bent Geometry. *Journal of Adhesion Science and Technology* 25, pp.2351–2368. Available at: https://doi.org/10.1163/016942411x580081

Arroussi, C., Belalia, A. & Meliani, M. H. 2023. Effects of composite and metallic patch on the limit load of pressurized steel pipes elbow with internal defects under opening bending moment. *Structural Monitoring and Maintenance*, 10(3), pp.221–242. Available at: https://doi.org/10.12989/smm.2023.10.3.221

Da Costa-Mattos, H.S., Reis, J.M.L., Sampaio, R.F. & Perrut, V.A. 2009. An alternative methodology to repair localized corrosion damage in metallic pipelines with epoxy resins. *Materials and Design*, 30, pp 3581–3591. Available at: https://doi.org/10.1016/j.matdes.2009.02.026

De Barros, S., Budhe, S., Banea, M.D., Rohem, N.R.F., Sampaio, E.M., Perrut, V.A. & Lana, L.D.M. 2018. An assessment of composite repair system in the offshore platform for corroded circumferential welds in super duplex steel pipe. *Frattura ed Integrità Strutturale* (Fracture and Structural Integrity), 44, pp. 151–160. Available at: https://doi.org/10.3221/IGF-ESIS.44.12

Djahida, D., Tewfik, G., Witek, M. & Abdelghani, M. 2021. Analytical Model and Numerical Analysis of Composite Wrap System Applied to Steel Pipeline. *Materials* 14, p.6393. Available at: https://doi.org/10.3390/Ma14216393

Duell, J.M., Wilson, J.M. & Kessler, M.R. 2008. Analysis of a carbon composite overwrap pipeline repair system. *International Journal of Pressure Vessels and Piping*, Volume 858(11), pp.782-788. Available at: https://doi.org/10.1016/J.Ijpvp.2008.08.001

Fezazi, A.I., Mechab. B., Mokadem, S. & Serier B. 2021. Numerical prediction of the ductile damage for axial cracks in pipe under internal pressure. *Frattura ed Integrità Strutturale*, *15*(58), pp.231-241; Available at: https://doi.org/10.3221/IGF-ESIS.58.17

Dassault Systems, The 3D EXPERIENCE platform. 2014. Simulia: Abaqus Finite Element Analysis for Mechanical Engineering and Civil Engineering [online].

Available at: https://www.3ds.com/products/simulia/abaqus [Accessed: 19 March 2025].

Ibrahim N.C., Boualem, S. & Belaïd, M. 2018. Analysis of the crack-crack interaction effect initiated in aeronautical structures and repaired by composite patch. *Fracture and Structural Integrity*, *12*(46), pp.140-149. Available at: https://doi.org/10.3221/IGF-ESIS.46.14

Kong, D., Li, C., Huang, X., Xin, M. & Xian, G. 2022. Mechanical analysis and parameter design of CFRP-Wrapped defected steel pipe.*International. Journal of Pressure Vessels and Piping*, 197, p.104653. Available at: https://doi.org/10.1016/J.Ijpvp.2022.104653

Lim, K.S., Azraai, S.N.A., &Yahaya, N. 2019. Behaviour of steel pipelines with composite repairs analyzed using experimental and numerical approaches. *Thin Wall Structure*, 139, pp.321-333. Available at: https://doi.org/10.1016/j.tws.2019.03.023

Mechab, B., Serier, B., Kaddouri,.K. & Bouiadjra. B.B. 2014. Probabilistic elastic-plastic analysis of cracked pipes subjected to internal pressure load, *Nuclear Engineering and Design*, 275, pp.281–286. Available at: https://doi.org/10.1016/j.nucengdes.2014.05.008

Mechab, B., Salem, M., Malika, M. & Boualem, S. 2020. Probabilistic elastic-plastic fracture mechanics analysis of propagation of cracks in pipes under internal pressure. *Frattura ed Integrità Strutturale*, 54, pp.202-210. Available at: https://doi.org/10.3221/IGF-ESIS.54.15

Mechab, B., Chioukh, N., Mechab, B. & Serier B. 2018. Probabilistic Fracture Mechanics for Analysis of Longitudinal Cracks in Pipes Under Internal Pressure. *Journal of Failure Analysis and Prevention,* 18(6), pp.1643–1651. Available at: https://doi.org/10.1007/S11668-018-0564-8

Mechab, B., Serier, B., Bouiadjra, B.B., Kaddouri, K. & Feaugas, X. 2011. Linear and nonlinear analyses for semi-elliptical surface cracks in pipes under bending, *International Journal of Pressure Vessels and Piping*, 88(1), pp.57–63. Available at: https://doi.org/10.1016/j.ijpvp.2010.11.001

Medjdoub, S.M., Bouiadjra, B.B. & Abdelkader, M. 2018. Effect of the geometrical parameters on the efficiency of bonded composite wrap for repairing cracked pipes. *Strength, Fracture and Complexity, 11*(4), pp.309-317. Available at: https://doi.org/10.3233/SFC-180232

Metehri, A., Kouider, M., Belaïd M., Mohammed M. & Ilias M.A.G., 2024a. Tensile examination of progressive damage and failure in porous ceramic composite material using the XFEM technique. *Vojnotehnički glasnik/Military Technical Courier*, 72(3), pp.1188-1213. Available at: https://doi.org/10.5937/vojtehg72-50091

Metehri, A., Serier, B., Belhouari, M. & Mecirdi, M.A. 2009. Numerical analysis of the residual stresses in polymer matrix composites. *Materials & Design*, 30(7), pp.2332–2338. Available at: https://doi.org/10.1016/j.matdes.2008.11.009

Metehri, A., Belaïd, M. & Abbès B.B.B. 2024b. A new investigation used to predict the burst pressure in straight corroded pipes under internal pressure.

Vojnotehnički glasnik/Military Technical Courier, 72(4), pp.1747-1771. Available at: https://doi.org/10.5937/vojtehg72-50357

Metehri, A., Belaïd M. & Abbès, B.B.B. 2024c. Modeling with prediction of burst pressure of elliptical corroded pipeline. *Xi'an Shiyou Daxue Xuebao (Ziran Kexue Ban)/ Journal of Xi'an Shiyou University, Natural Sciences Edition,* 67(11), pp.86-96. Available at: https://doi.org/10.5281/zenodo.14195656

Metehri, A., Kouider, M. & Lousdad, A. 2019. Effect of crack position and size of particle on SIF in SiC particles reinforced Al composite. *Frattura ed Integrità Strutturale*, 13(48), pp.152-160. Available at: https://doi.org/10.3221/IGF-ESIS.48.18

Nadia, B., Belaïd, M., Malika, M., Aicha, M., Mokadem, S. & Abbès B.B.B. 2024. Analytical and numerical methods for estimating the probability of interlaminar fracture in Mode I of composite structures under the peel test. *Vojnotehnički glasnik/Military Technical Courier*, 72(4) pp.1601-1622. Available at: https://doi.org/10.5937/vojtehg72-49978

Netto, T.A., Ferraz, U.S. & Botto, A. 2007. On the effect of corrosion defects on the collapse pressure of pipelines. *International Journal of Solids and Structures,* 44(22-23), pp.7597–7614, Available at: https://doi.org/10.1016/j.ijsolstr.2007.04.028

Fatoba, O. & Akid, R. 2014. Low Cycle Fatigue Behaviour of API 5L X65 Pipeline Steel at Room Temperature. *Procedia Engineering*, 74, pp.279-286. Available at: https://doi.org/10.1016/J.Proeng.2014.06.263

Salem, M., Mechab, B., Berrahou, M., Bachir Bouiadjra, B. & Serier, B. 2019. Failure Analyses of Propagation of Cracks in Repaired Pipe Under Internal Pressure. *Journal of Failure Analysis and Prevention*, 19(1), pp.212–218. Available at: https://doi.org/10.1007/s11668-019-00592-3

Singh, D.K., Villamayor, A. & Hazra, A. 2021. Numerical and experimental analysis of loctite adhesive composite wrapping on EN 10028 steel pipes. *Materials Today: Proceedings,* 44(6), pp.4158-4165. Available at: https://doi.org/10.1016/j.matpr.2020.10.525

Chandra Khan, V., Balaganesan, G., Kumar Pradhan, A. & Sivakumar, M. S. 2017. Nanofillers Reinforced Polymer Composites Wrap to Repair Corroded Steel Pipe Lines. *Journal of Pressure Vessel Technology*, 139(4) p.041411. Available at: https://doi.org/10.1115/1.4036534

Zecheru, G., Dumitrescu, A., Diniţă, A. & Yukhymets, P. 2018. Design of Composite Repair Systems. *Engineering Materials*, pp.269–285. Available at: https://doi.org/10.1007/978-3-319-56579-8_17

Utilización del método de elementos finitos para el desarrollo de un nuevo modelo que predice la presión de ruptura de defectos rectos en tuberías corroídas reparadas con envolturas compuestas adheridas

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CAMPO: Informática, ingeniería mecánica, materiales
TIPO DE ARTÍCULO: artículo científico original

Resumen:

Introducción/objetivo: Este trabajo tiene como objetivo crear un nuevo modelo que prediga la presión de ruptura de fallas rectas bajo presión interna en tuberías corroídas que han sido reparadas con envolturas compuestas.

Métodos: Los aspectos geométricos influyeron en el rendimiento de la reparación. El comportamiento del parche compuesto depende en gran medida de varios parámetros, como el tamaño de la tubería, el tamaño del defecto, el número de capas del compuesto, la orientación de las capas, las propiedades del compuesto y el espesor del adhesivo. Se analizaron los efectos de todos estos parámetros en la eficiencia de la reparación.

Resultados: Los resultados obtenidos mostraron que la envoltura compuesta reduce la concentración de tensiones causada por el defecto de corrosión, lo que mejora la durabilidad a largo plazo de las tuberías.

Conclusión: La comparación entre el nuevo modelo desarrollado analíticamente y los cálculos de elementos finitos (EF) mostraron una buena concordancia para la tubería corroída reparada.

Palabras claves: corrosión, presión uniforme, modelo analítico, tuberías, reparaciones con compuestos adheridos

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Использование метода конечных элементов в разработке новой модели, прогнозирующей давление разрыва прямого дефекта в корродированной трубе, отремонтированной с помощью клеевой композитной заплаты

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РУБРИКА ГРНТИ: 23.25 Информационные системы с базами знаний,
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Резюме:

Введение/цель: Цель данной статьи заключается в создании новой модели, прогнозирующей давление разрыва прямых дефектов вследствие внутреннего давления в корродированных трубах, отремонтированных с помощью композитной заплаты.

Методы: Геометрические характеристики влияют на эффективность ремонта. Поведение композитной заплаты сильно зависит от нескольких параметров таких как размер трубы, размер дефекта, количество слоев композита, ориентация слоев, свойства композита и толщина клея. В статье проведен анализ влияния всех этих параметров на эффективность ремонта.

Результаты: Полученные результаты показали, что композитная заплата снижает концентрацию напряжения, вызванного коррозионным дефектом, что повышает долговечность трубы.

Выводы: Сравнение новой аналитически разработанной модели с расчетами методом конечных элементов (FE) показало положительное совпадение касательно отремонтированных корродированных труб.

Ключевые слова: коррозия; равномерное давление; аналитическая модель; труба; ремонт композитных материалов на клеевом соединении.

Коришћење методе крајњих елемената ради развијања новог модела за предвиђање притиска пуцања праволинијског дефекта у кородираним цевима поправљеним лепљењом композитном закрпом

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Сажетак:

Увод/циљ: Циљ овог рада јесте креирање новог модела за предвиђање притиска пуцања праволинијских дефеката услед унутрашњег притиска у кородираним цевима поправљеним лепљеном композитном закрпом.

Методе: Геометријске карактеристике утичу на перформансе поправке. Понашање композитне закрпе у великој мери зависи од неколико параметара, као што су величина цеви, величина дефекта, број слојева композита, оријентација слојева, својства композита и дебљина лепка. Анализиран је утицај свих наведених параметара на ефикасност поправке.

Резултати: Добијени резултати су показали да је композитна облога смањила концентрацију напона проузрокованог дефектом услед корозије, чиме се побољшава дугорочна издржљивост цеви.

Закључак: Поређење новог, аналитички развијеног модела и прорачуна методом коначних елемената (FE) показало је добро слагање код поправљених кородираних цеви.

Кључне речи: корозија, равномерни притисак, аналитички модел, цев, поправке лепљење композита.

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