

NRICON 2016

EFFECT OF PUTTY PROPERTIES IN REPAIRING CORRODED PIPELINE: A FINITE ELEMENT ANALYSIS

Muhammad Haziq Abdul Jalil¹, Alireza Valipour¹, Lim Kar Sing^{1,2},
Siti Nur Afifah Azraai¹, Libriati Zardasti¹, Nordin Yahaya^{1*} & N.M.
Noor¹

¹ Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310, Johor, Malaysia

² Faculty of Civil Engineering and Earth Resources, Universiti Malaysia Pahang, Lebuhraya Tun
Razak, Gambang, Kuantan, Pahang 26300, Malaysia

*Corresponding Author: nordin@utm.my

Abstract: Underground pipelines are the most preferable way to transport oil and gas over a long distance. These steel pipelines often suffered from several deteriorations including corrosion. Corrosion causes the outer lining of a pipeline to thin and subsequently reducing pipeline strength. In order to prevent this loss of strength, repair is required. Composite wrap repair is a technique that can be used to repair damage pipeline. Composite wrap repair consist of Fibre Reinforced Polymer (FRP) composite wrap and putty as infill material to restore the strength of a damaged steel pipe. Recently, there is tendency in reducing the usage of composite wrapping layer due to several reasons. Ultimately, it is hoped that one day the repair can be done without composite wrapping. Thus, the purpose of this research is to explore the potential of using putty alone as a repair material in repairing corroded pipeline without composite wrap via finite element analysis. Difference geometrical defects that simulating external corrosion were investigated to study the influence of defect sizes towards the burst pressure of corroded pipeline. Two infill materials which both have difference mechanical properties are used in this research to investigate their influence towards the performance of the repaired pipes. Finite element analysis has been conducted to determine the behaviour of the defected pipeline with a patch of the infill covered the defected area. The analysis was conducted for three defect sizes: 100mm x 100mm, 75mm x 150mm, and 25mm x 150mm for both putties. It was found that the narrow defect of the pipeline causing the pipe to burst at lower pressure as compared to defect that have the same dimension area for both of the infill material. This may due to high stress concentration at small area of the defect. Furthermore, it was also revealed that infill with higher ultimate tensile strength able to withstand higher pressure. The finding of the research shows that by using appropriate infill, there are potential to increase the burst pressure by about 5%. The findings of this research can serve as stepping stone to study the feasibility of repairing damaged pipeline using putty alone.

Keywords: *Composite repair, geometrical defect, infill properties, pipeline.*

1.0 Introduction

Usage of pipelines has been broad in our daily life. The function of pipelines is to transport material such as water, gas, and oil from one point to another. Gas pipeline is used to transport gas from offshore platform to the onshore processing plant and some of the onshore pipelines are buried deep in the soil to ensure no interruption due to its high pressure operating condition. Although it is safe with outside interference, soil is one of the components that can contribute a metallic corrosion; this case is known as soil corrosion (Ling *et al.*, 2008; Tahir *et al.*, 2015). In the oil and gas industry, corrosion is an inevitable issue due to a very complicated working condition, such as high pressure, high pH value, high temperature multi-phase flow and ion concentration (Norhazilan *et al.*, 2008 & Yahaya *et al.*, 2009). Many of the pipelines in the world have been in service since 1940s and 1950s (Saeed *et al.*, 2014). Since most of these pipelines have been operate for many years, many of them are in need of extensive repair and maintenance to ensure it can work efficiently. Over the years of operation, underwater or underground pipelines are exposed to corrosion attack. A corroded pipeline will reduce the strength and eventually reduce its service life; hence repair and maintenance are usually done to ensure the pipelines are in good working condition (Azraai *et al.*, 2015).

Previous studies show that the composite wrap repairs have the capability of sustaining the corroded pipeline to work with operating load (Alexander, 2014; Chan *et al.*, 2015). Composite wrap repair is a combination of Fibre Reinforced Polymer (FRP) composite wrap, adhesive, and infill. Putty/grout is often used as infill to fill the corroded section. Figure 1 shows a typical composite wrap repair. The putty acts as load transfer medium between steel pipe and composite wrap. Usage of composite wrap together with putty for repairing damaged pipes have been done for years because it is capable to restrain the high pressure of the pipeline from yield (Ma *et al.*, 2011; Trifonov and Cherniy, 2014; Shamsuddoha *et al.*, 2016). A composite wrap repair is generally installed by wrapping several layers of a composite material around the damaged area (Ariff *et al.*, 2014). The thickness of wrapping plays an important role, an increase of wrapping thickness is important to prevent the yielding of the pipeline at the defected area, hence a minimum thickness should be done according to an existing codes to prevent premature yielding (Osella *et al.*, 1998). The advantage of composite wrap repair including is no risk of fire or explosion during the repair because welding and cutting process were completely eliminated. The process is also 24% cheaper than the traditional welded steel sleeve process and 73% cheaper than replace defected pipe section (Koch *et al.*, 2001). Composite repair also prevented the growth of newer corrosion risk and it can be considered as a life time repair (Shouman and Taheri, 2011). During operation, FRP composite wrap helps in strengthening the corroded area of the pipeline by sharing the load while infill helps in transferring the load.

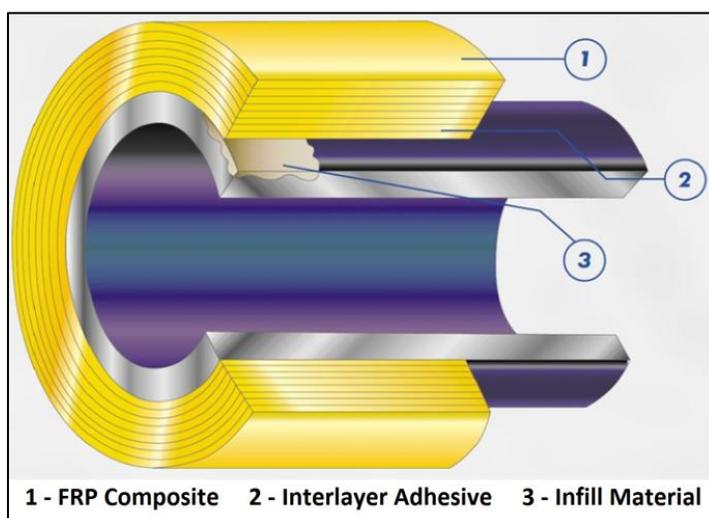


Figure 1: Typical arrangement of composite wrap

Recently, there is tendency in reducing the usage of composite wrapping layer. This is because some damaged pipes are located in congested areas such as piping on offshore platforms, piping of boiler tank and underground pipelines that have limited working space for the wrapping process. This makes the replacement of the damaged pipes the only possible solution to maintain its service life. In addition, the composite wrapping layer is generally more expensive as compared to infill material. Due to this problem, a research is suggested to explore the potential of repairing damaged pipelines by using putty alone. Thus, this research has taken an initial step to investigate the influence of different putty properties toward bursting capacity of externally corroded steel pipelines with different defect geometries. Finite element analysis (FEA) was carried out to achieve the stated aim.

2.0 Research Methodology

Finite element models of corroded and repaired pipelines were developed using ANSYS finite element software. The steel pipeline and putty used in this research are ASTM Grade B steel and epoxy grouts, respectively. The Young's modulus, yield strength and ultimate strength of steel pipe are 201GPa, 293MPa and 480MPa respectively. On the other hand, Putty A has a 19GPa of Young's modulus and 20.02MPa ultimate strength while the Young's modulus and ultimate strength for Putty B are 8.06GPa and 38.89MPa, respectively. The steel pipe and putty are modelled as multi-linear isotropic material. The base geometry of the pipeline is 168.3mm diameter with a 1200mm length and it is labelled as no flaw for undamaged pipelines. On the other hand, three models with defect geometries of 100mm x 100mm, 75mm x 150mm and 25mm x 150mm were created. A 50% of metal loss was created for all defect

geometries to simulate external corrosion condition. For cases of all damaged pipelines, putty was model to cover the defect. 3D solid element with quadrilateral meshing was chosen as it is capable to optimize the analysis. The interaction between putty and steel pipelines was assumed to be perfectly bonded to simplify the analysis. For illustration purposes, Figure 2 shows the quarter meshed model. Pressure was loaded on the internal wall of pipeline with an increasing rate of 0.1MPa per second. Suitable boundary conditions were applied at both edges of the pipeline. Stress and strain at the most critical location of all models was extracted to evaluate the effect of different defect geometries and putty properties towards ultimate burst pressure.

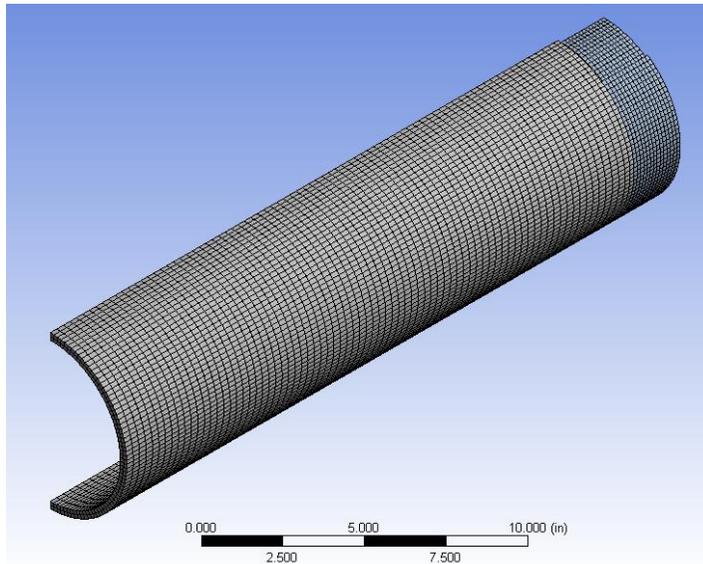


Figure 2: Meshed model of putty repaired pipeline

3.0 Results and Discussion

3.1 Effect of Geometrical Defect

The burst pressure of each defective model was recorded to study the capability of the corroded pipes in withstanding the internal pressure before the pipe fail due to over loading. The result was then compared with theoretical pressure vessel calculation base on DNV RP-F101 for verification purposes. Table 1 summarises the results of the simulation and theoretical calculation. A good agreement between theoretically calculated burst pressure and simulation results is achieved with less than 10% of difference. This indicates that the FEA model is capable to predict the given defect conditions. As can be seen in Table 1, the result shows the defected pipeline failed with lower bursting pressure compare to the non-defect pipe and showing a gradual decrease

of bursting pressure for a narrow defect pipe. Figure 3 depicts the strain over time of the models with different defect geometries. Since the loading rate is 0.1MPa per second, the strain over time can also represents the strain over pressure. As can be seen, the non-defect pipe shows lowest strain (hence lowest bulging) before the pipe yield while the narrowest defect geometries recorded highest strain reading at given pressure. This finding is in-line with Duell *et al.* (2008) where narrow defects tend to lower the load carrying capacity of corroded pipeline. This may due to high stress concentration at small area of the defect.

Table 1: Bursting pressure of difference defect geometries

Pipe conditions	Theoretical burst pressure (MPa)	FEA burst pressure (MPa)	Percentage difference (%)
Non-defect pipe	42	44.6	5.83%
100 x 100 mm defect	30.2	29.58	2.05%
75 x 150 mm defect	26.18	27.82	6.26%
25 x 150 mm defect	26.18	28.11	7.37

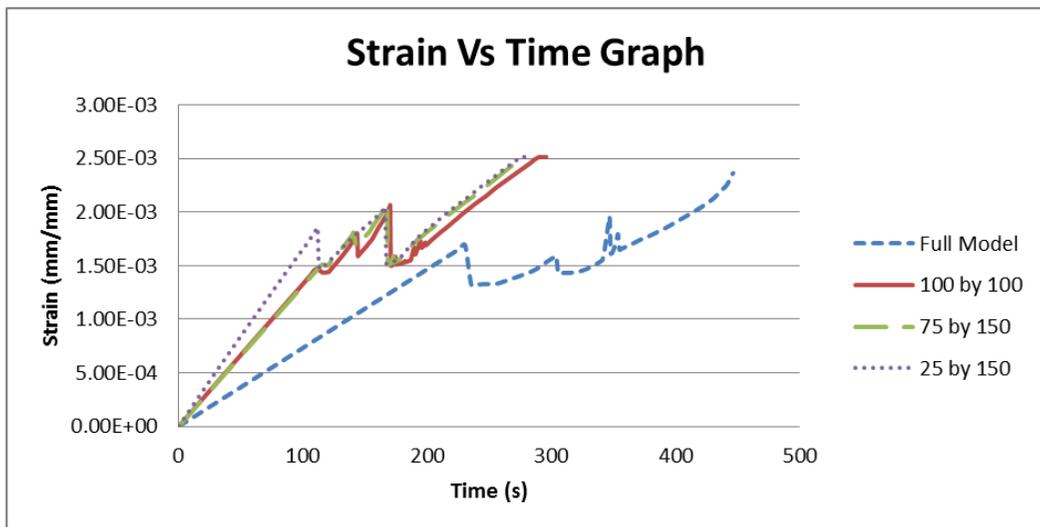


Figure 3: Effect of geometrical defects on burst pressure

3.2 Effect of Putty Properties

Results for both putties as a patch to repair the defected area of the pipe were recorded and analysed. Both Putty A and Putty B have different mechanical properties of ultimate tensile strength (UTS) and stiffness. Putty A has lower UTS of 20.02MPa and high stiffness of 19GPa. Meanwhile, Putty B has a 38.89MPa UTS and 8.06GPa modulus,

receptively. The results in Table 2 shows the burst pressure for all defects repaired with Putty A and Putty B. Based on the results, all repaired pipes with both putties show higher bursting pressure as compare to their defective pipes (refer Table 1). The burst pressure repaired with Putty A and Putty B shown an increment between 2.5% to 2.85% and 4.94% to 5.44%, respectively. Putty B has higher resistance against load (about 2%-3%) compare to Putty A with regards to all defect geometries. In addition, it was found that the increment of burst pressure is more visible for narrower effect for both putties. Figure 4 illustrates an example of strain over time for 100mm x 100mm defected pipes repaired with both putties. It is clearly shown that pipe repaired with Putty B shows almost 3 times higher strain at yield point (about 17.5PMa) as compared to Putty A. This may seems reasonable as Putty A has higher Young's modulus, thus providing additional stiffness at the defect area and helps in reducing bulging. However, after the pipe has yielded, Putty B with higher ultimate strength plays a more influential role in providing additional loading capacity. Therefore, the burst pressure of Putty B is higher as compared to the Putty A repaired pipe.

Table 2: Bursting pressure of difference putty properties

Defect size (mm)	Bursting pressure (MPa)		Percentage difference between putties (%)
	Putty A	Putty B	
100 x 100 mm defect	30.33	31.04	2.34
75 x 150 mm defect	28.57	29.33	2.66
25 x 150 mm defect	28.91	29.64	2.53

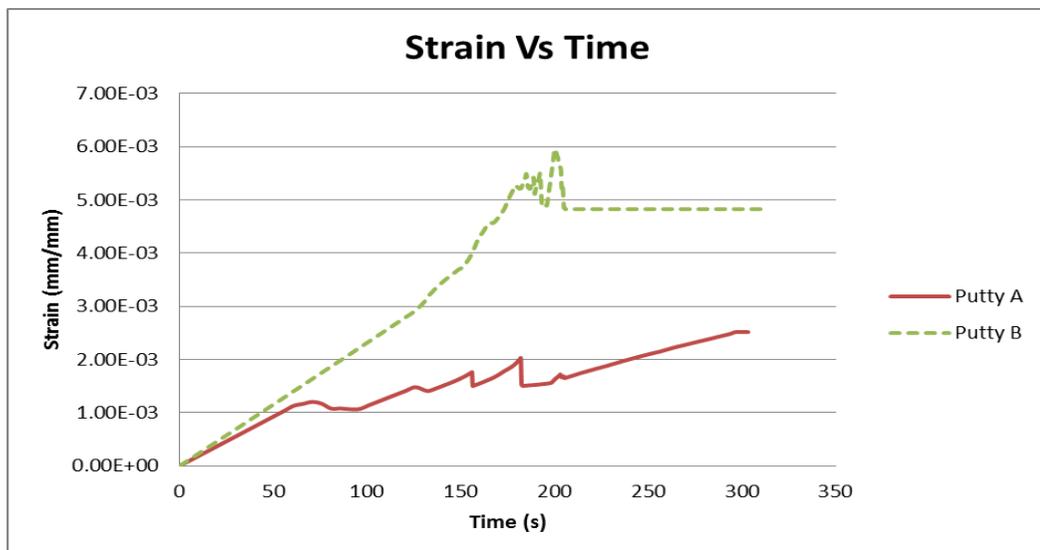


Figure 4: Effect of putty properties on burst pressure

4.0 Conclusions

Finite element models were developed to investigate the influence of defect geometries and putty properties in repairing damaged pipelines. Based on the finite element analysis, several findings have been analysed and discussed to determine the performance of infill towards the size of the defects and material properties of infill that might increase the performance of infill. The developed finite element models shows good agreement with theoretical prediction, hence it is deemed as validated. It was found that defect geometries does not have huge impacts towards the performance of infill because the size of defects affected generally the integrity of the pipeline but a narrower defect will cause the more stress towards the infill although it is only small differences. The material properties that might improve the performance of infill would be the ultimate strength because it governs more effects than modulus of elasticity on ultimate burst pressure. However, since this research only carried out numerical analysis, experimental test is suggested to further validate the findings of this research.

5.0 Acknowledgements

The work was financially supported by Universiti Teknologi Malaysia (Grant No. 13H27 and 11H40) and Ministry of Higher Education, Malaysia (Grant No. 4F530).

References

- Alexander, C. (2014). The Role of Composite Repair Technology in Rehabilitating Piping and Pipelines. *Proceedings of the ASME 2014 Pressure Vessels & Piping Conference (PVP 2014)*. 20-24 July 2014. Anaheim, California, USA. Paper No.: PVP2014-28257.
- Ariff, T.F., Azmi, M.A., and Bahar, R. (2014). Economic Analysis of Using E-Glass Composite Wrap Repair System for Pipelines. *Australian Journal of Basic and Applied Sciences*. 8(15), 241-245.
- Azraai, S.N.A., Lim, K.S., Yahaya, N., and Noor, N.M. (2015). Infill Materials of Epoxy Grout For Pipeline Rehabilitation and Repair. *Malaysian Journal of Civil Engineering*. 27(1), 162-167.
- Chan, P.H., Tshai, K.Y., Johnson, M., Choo, H.L., Li, S., and Zakaria, K. (2015). Burst Strength of Carbon Fibre Reinforced Polyethylene Strip Pipeline Repair System – A Numerical and Experimental Approach. *Journal of Composite Materials*, 49(6), 749-756.
- Duell, J.M., Wilson, J.M., and Kessler, M.R. (2008). Analysis of a Carbon Composite Overwrap Pipeline Repair System. *International Journal of Pressure Vessels and Piping*. 85, 782-788.
- Ling, X., Ni, H.F., and Ma, G. (2008). Investigation of the Influence of Shot Peening on Stress Corrosion Cracking of Stainless Steel Welded Joints. *Materials Science Forum*. 575-578, 672-677. doi:10.4028/www.scientific.net/MSF.575-578.672
- Koch, G.H., Brongers, M.P., Tompson, N.G., Virmani, Y.P., and Payer, J.H. (2001). *Corrosion Cost and Preventative Strategies in the United States*. Federal Highway Administration, Office of Infrastructure Research and Development. pp. 260-311.

- Ma, W.F., Luo, J.H., and Cai, K. (2011). Discussion about Application of Composite Repair Technique in Pipeline Engineering. *Advanced Materials Research*. 311-313, 185-188.
- Norhazilan, N.M.; Yahaya, N. & Othman, S.R. (2008). The effect of extreme corrosion defect on pipeline remaining life-time. *Malaysian Journal of Civil Engineering*. 20(1), 47-57.
- Osella, A., Favetto, A., and López, E. (1998). Currents Induced By Geomagnetic Storms on Buried Pipelines as a Cause of Corrosion. *Journal of Applied Geophysics*, 38(3), 219-233. doi:10.1016/S0926-9851(97)00019-0
- Saeed, N., Ronagh, H., and Virk, A. (2014). Composite Repair of Pipelines, Considering the Effect of Live Pressure - Analytical and Numerical Models With Respect to ISO/TS 24817 and ASME PCC-2. *Composites: Part B*, 58, 605-610.
- Shamsuddoha, M., Islam, M.M., Aravinthan, T., Manalo, A., and Djukic, P. (2016). Effect of Hygrothermal Conditioning on the Mechanical and Thermal Properties of Epoxy Grouts for Pipeline Rehabilitation. *AIMS Materials Sciences*, 3(3), 823-850.
- Shouman, A., and Taheri, F. (2011). Compressive Strain Limits of Composite Repaired Pipelines Under Combined Loading States. *Composite Structures*. 93, 1538-1548.
- Tahir, S.N.F.M.M., Yahaya, N., Noor, N.M., Lim, K.S., and Rahman, A.A. (2015). Underground Corrosion Model of Steel Pipelines Using In Situ Parameters of Soil. *Journal of Pressure Vessel Technology*, 137(5), 051701.
- Trifonov, O.V., and Cherniy, V.P. (2014). Analysis of Stress-Strain State in a Steel Pipe Strengthened With a Composite Wrap. *Journal of Pressure Vessel Technology*, 136, (October), 051202. doi:10.1115/1.4027229
- Yahaya, N.; Norhazilan N.M.; Din M.M. & Nor S.H.M. (2009). Prediction of CO₂ corrosion growth in submarine pipelines. *Malaysian Journal of Civil Engineering*. 21(1), 69-81.