Mathematical Statistician and Engineering Applications
ISSN: 2326-9865
DOI: https://doi.org/10.17762/msea.v71i2.2137

Corrosion Behavior and Internal Pressure Capacity of a Composite System Used to Connect Metallic Pipes

Mayank Kumar
Department of Civil Engineering, Graphic Era Hill University, Dehradun, Uttarakhand, India 248002

Article Info
Page Number: 574-583
Publication Issue:
Vol. 71 No. 2 (2022)

Article History
Article Received: 25 December 2021
Revised: 20 January 2022
Accepted: 24 February 2022

Abstract: This research aims over how different kinds of fiber-reinforced plastic (FRP) may change the internal pressure capacity and corrosion behavior of linked metal pipes. Hence, aluminum pipes have been fabricated for further usage in wrapping with various FRP and welding. Used FRP materials include carbon fiber/epoxy (CFRP) and kevlar fiber/epoxy (KFRP) (CFRP). These fibers have been slit into narrow strips for use in the fabric-winding technique of connecting. Four-layer KFRP pipes and eight-layer KFRP-CFRP pipes are also viable options that have been investigated. On the other hand, comparisons have been made using pipes that have two different kinds of welding. The findings demonstrated an increase in the internal pressure capacity of the pipe compared to welding. The corrosion test was finally performed. The findings demonstrated that FRP connecting methods outperformed both welded and unjoined pipes in terms of corrosion resistance. These findings indicate that FRP composites have a bright future for use in pipe joining.

Keywords: Composites; Metalic pipes; Joining; Internal pressure capacity; Corrosion

Introduction

Pipelines have long been utilized to provide potable water to urban areas [1]. Midway through the nineteenth century in the United States, pipelines were first put to use transporting oil and gas [2]. Pipelines are built to transport crude oil and natural gas from extraction sites to refineries and distribution hubs. The rapid and efficient delivery of massive quantities of oil or gas is necessary due to the increasing demand for energy throughout the globe. As a result, pipelines have long been the preferred method of transporting oil and gas due to their efficiency and convenience. Pipelines used to transfer oil and gas traditionally are often built of steel [4]. The high strength qualities of carbon steel pipes and high-strength low alloy steel pipes have made them popular for transporting oil and gas [5,6]. Pipelines with high pressure capacity and high strength qualities are crucial for transporting oil and gas in a variety of environments, including those that are offshore, onshore, underground, or aboveground [4,7,8]. It's also important to note that popular standards and regulations like ASME and API are used throughout the pipeline design process. Corrosion has been feared for as long as there have been metals, since it deteriorates materials and transforms once-beautiful buildings into eyesores. Corrosion may refer to the breakdown of any material, including glass, wood, concrete, and plastic, although it is most often associated with the deterioration of metals due to their central role in human society. The mechanical, chemical, and physical qualities of metals and alloys are taken into account while selecting them for various uses. In addition to their industrial use, they also have domestic uses as tools and implements. Metals may be found in anything from complex machinery like airplanes and automobiles to everyday goods like toys and kitchen utensils [1-3]. Different metals will experience oxidation to varying degrees. The corrosive force that destroys metals is an inevitable byproduct of their transient existence as metals. From their naturally occurring forms as diverse chemical compounds (ores), metals need absorption of energy throughout the metallurgical process (smelting, refining, etc.) to transform into their final metallic state [4]. Corrosion is the process through which this stored energy is eventually lost [5]. Corrosion, therefore, is the spontaneous process that results in the degradation of a valuable substance and a loss in free energy. Corrosion is the undesirable chemical reaction between two or more metals that converts the original metal to compounds. Iron rusts, copper develops a green patina, silver tarnishes, zinc ages to a gray patina, and brass pits when exposed to corrosion [6]. Corrosion occurs when a metal reacts with its environment and loses several of its desirable qualities, including malleability, ductility, electrical conductivity, optical reflectivity, etc. [7]. While corrosion occurs slowly and often at the metal's surface, it may cause significant losses. Metal equipment, instruments, chemical plants, buildings, etc. become ineffective, inefficient, and worthless when corroded [8]. Metals are used everywhere, so what was formerly regarded to be an issue for solely metallurgists and chemists has become a multidisciplinary topic of study: corrosion. Because of the growing recognition of the significant losses caused by corrosion damage, the topic of material corrosion has acquired substantial prominence during the last several decades. Every year, businesses, governments, and other organizations lose billions of dollars worldwide due to terrorism [9]. The direct cost of replacement and maintenance, as well as the economic loss due to production disruptions, contribute to the total cost of corrosion. Pricey materials and other preventative actions against corrosion and product loss are also included in. Corrosion is costly not just monetarily, but also in terms of safety hazards and environmental degradation. Fractures in buildings, pressure tank failures, and leaks in containers housing noxious, aggressive, or combustible chemicals are all potential sources of injury to workers [10]. It has been calculated that the use of current goods and procedures for corrosion prevention may readily serve over 25% of the expected yearly loss resulting from corrosion damage..

Electrochemical Theory of Corrosion

Corrosion is the process through which metals react chemically or electrochemically with their surroundings, causing their destruction or slow degradation. Because the range of corrosion reactions in materials is so broad, there is no one set of mechanisms that can account for all of it. Electrochemical processes are often responsible for metal corrosion in watery environments. These reactions take place at the contact between the metal and its solution. Corrosion is a heterogeneous process that is often governed by diffusion [5]. There are three preconditions that must be met concurrently for the electrochemical reaction to proceed: I There might be a distinction There must be ii) a continuous conduction channel and iii) mechanisms for electrostatic interaction among electronic and electrolytic conductors [11]. Electrochemical cells, made up of an anode (the negatively charged electrode), a cathode (the positively charged electrode), an electrolyte (the electrically conductive medium), and a connecting electronic contact, are responsible for the usual corrosion response in aquatic settings. (Fig. 1.1(a)) [12].

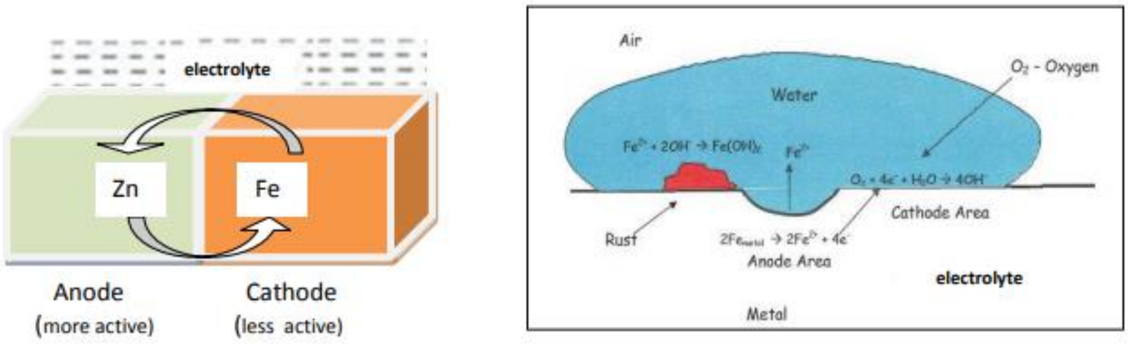


Fig.1.1 Formation of electrochemical cell during corrosion (a) typical corrosion (b) iron surface undergoing corrosion by salt water

The metal with the lowest reduction potential becomes the anode and the other metal serves as the cathode when two dissimilar metals are brought into contact with one another. Corrosion of a single metal results in the formation of anodic and cathodic zones on the metal's surface. Different thermal and metallurgical treatment, local changes in surface roughness, the existence of local scratches, the presence of more than one phase, deformation, and other variables all contribute to the production of cathodic and anodic zones on a metal's surface. [13]

Literature Review

Lian-Jin Tao et.al., 2021 The jacking force is a critical factor in the construction of pipe jacks and one of the most critical elements in pipe jacking engineering. Predicting the jacking force of a single pipe has been the subject of much study. Unfortunately, studies of the jacking force of a line of steel pipes are uncommon. This study investigates a specific pipe jacking job. Although the test pipes were easily jacked into place, the remaining pipes were stuck due to a lack of jacking force from the machine. On the basis of this phenomena, field measurements and numerical simulations are used to examine the impact of pipe separation and the number of previously jacked pipes on the jacking force. The method through which the test pipes were trapped in steel is examined in depth. According to the findings, the jacking force falls nonlinearly with the rise in pipe spacing, and the jacking's effect range is three times the pipe diameter; the jacking force grows with the increment in the number of jacked pipes, but the growing trend eventually slows down. The aforementioned findings provide support for the suggested pipe group effect of jacking force. According to the findings, the jacking force's amplification and superposition impact should be taken into account during the design phase to prevent pipes from being stuck during the jacking operation.

Piyius Raj Singh et.al., (2021) In North American water distribution systems, it is estimated that 82% of the cast-iron pipe stock has reached the end of its usable life. Pipe stock buried in expansive soils is more likely to fail due to moisture-induced soil expansion, according to previous research; however, this risk has not been systematically assessed. The goal of this work is to put a number on how likely it is that cast-iron pipes may crack under the kind of soil stress that is brought on by water. The reliability study is established by using a newly developed mechanically based pipe-soil interaction model and fracture mechanics with corrosion deterioration. The probability of a pipe segment failing is estimated based on its configuration factors and its age, with the use of Monte Carlo simulation. Evidence suggests that pit-cast pipes with lower internal diameters are more susceptible to failure, and that variables other than age may play a substantial role in this phenomenon. With a sensitivity analysis, we can determine which input parameters have the most impact on the failure probability, and it turns out that corrosion parameters and soil expansion parameters have the biggest impact. Finally, the framework's limitations and the places where additional study is required are explored.

Hong Jin Jun et.al.,(2020) Road flooding, disruptions to everyday life, and monetary loss result from breaks in water-transmission mains (WTMs) that carry substantially more water. Unfortunately, there has been a dearth of research on the causes and processes of failure in steel WTMs in the field. The objectives of this research were to (1) use statistical correlation analysis to determine the primary factors influencing a break rate of steel WTMs; (2) identify the failure mechanisms of the influential factors in relation to the steel WTM; and (3) quantify the failure causes using the historical break data.

Kong Fah Tee et.al., (2020) The Gaussian copula technique is used to account for the dependency (correlation) between the expansions of separate fractures. The parameters of the stochastic models are evaluated based on the data from numerous in-line inspections (ILI) using Bayesian updating. In order to effectively take into consideration the measurement errors and PoD of the crack characteristics associated with ILI, a hierarchical Bayesian framework is created. Subset simulation, a kind of structural reliability method (SRM), is used in conjunction with the data augmentation (DA) approach to carry out the Bayesian update. For the purpose of implementing and validating the approach, many simulated fracture features from various ILI inspections are used.

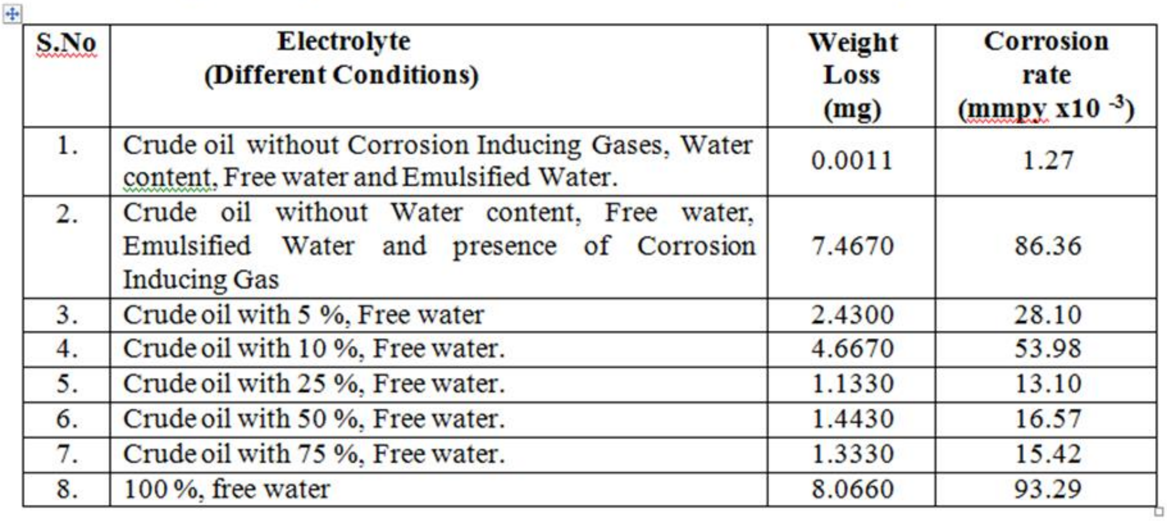
Corrosion Behaviour of API-5l-Grade-X52 Steel Pipe Line In Crude Oil Under Different Conditions

To transport liquids and gases from their point of origin to their final users, the petroleum industry relies heavily on the materials used in the building of pipelines. Current era It's important to remember that corrosion isn't only a concern during shipping; it may arise at any point in the manufacturing process, from raw material extraction through final product storage. Extreme circumstances, such as a corrosive environment and high temperature, make corrosion of materials a major source of waste in industrial applications. The oil and gas industry loses US $2.5 trillion each year due to corrosion, which is roughly equivalent to 3 to 4% of the GDP of industrialized nations ($40 billion in India) and makes it one of the world's most pressing issues that must be investigated. In addition, effective corrosion management may help us avoid several catastrophes that pose major problems including human casualties, societal fallout, and contamination of water supplies and the natural environment. The oil industry is plagued by corrosion at every level, from down-hole tools to surface processing plants. Tanks, casings, tubes, pipes, and other apparatuses spring leaks. Frequent partial or complete shutdowns of the process, as a consequence of corrosion issues, may result in significant financial losses. The salt concentration of crude oils varies widely in the petroleum business, mostly based on the origin and the potential of producing wells and/or zones. Mineral salt concentrations may reach two million parts per million (ppm), depending on the underlying geology. In addition, tanker shipping may deliver salt water to the refinery, which might increase the overall salt concentration. The salt content of crude oil is almost always made up of salt dissolved in water droplets that are evenly distributed throughout the crude oil. These salts of the salty water have a variety of chemical compositions, but sodium chloride and, to a lesser extent, calcium and magnesium chlorides are always present.

Results

Purified crude oil sample where the CO2 and H2S were purged away using an inert gas like Helium instead of the formation water. Non- emulsifier (NE) and OSD (Oil Soluble Demulsifiers) with and without addition to respective Crude oil samples indicated the lack of Emulsified water (Ew) and free water (Fw). Dean Stark approach also validated the water content (Wc). In this scenario, CIG (Corrosion Inducing Gases)-containing crude oil is extracted without the production of water. There is no formation water of any kind, as certified by the applicable ASTM standard (Fw, Ew, and Tw).

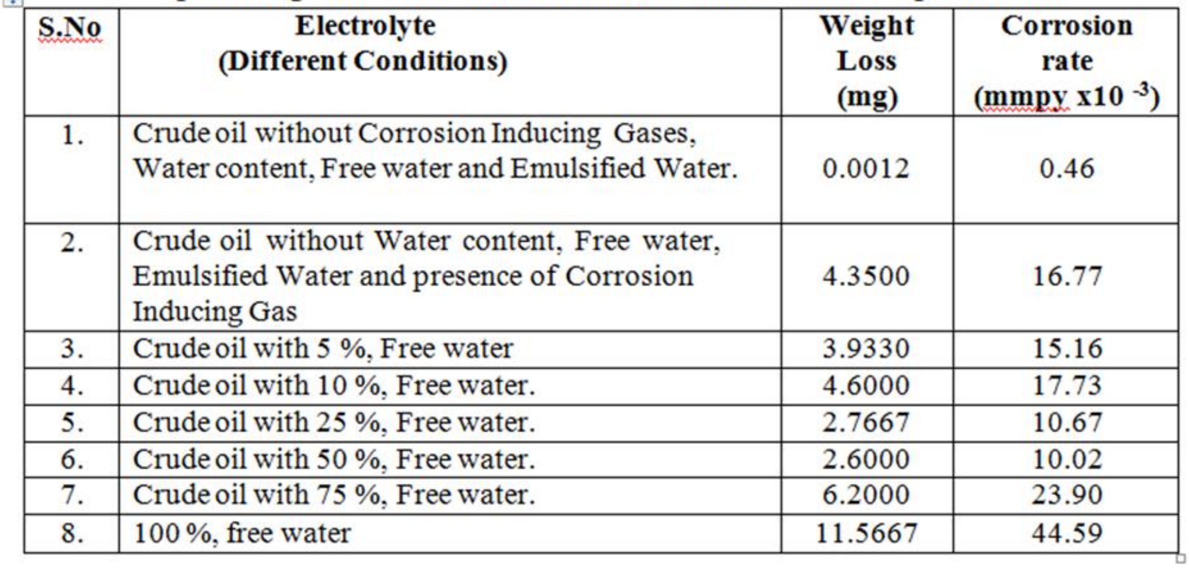
Table-1 Corrosion parameter of API -5L-Grade-X52 in crude oil with various percentage of connate/formation water after 24 hours exposure time.



S.No	Electrolyte (Different Conditions)	Weight Loss (mg)	Corrosion rate (mmpy x10 $^{-3}$)
1.	Crude oil without Corrosion Inducing Gases, Water content, Free water and Emulsified Water.	0.0011	1.27
2.	Crude oil without Water content, Free water, Emulsified Water and presence of Corrosion Inducing Gas	7.4670	86.36
3.	Crude oil with 5 %, Free water	2.4300	28.10
4.	Crude oil with 10 %, Free water.	4.6670	53.98
5.	Crude oil with 25 %, Free water.	1.1330	13.10
6.	Crude oil with 50 %, Free water.	1.4430	16.57
7.	Crude oil with 75 %, Free water.	1.3330	15.42
8.	100 %, free water	8.0660	93.29

Corrosion characteristics and iron counts for crude oil of API-5L grade after 24, 72, 120, 168, 240, 360, and 720 hours of exposure are listed in Tables 1 through 5, depending on the circumstance. Corrosion rates were seen to rise from 28.10 x 10-3 mmpy to 93.29 x 10-3 mmpy after 24 hours of exposure, which may be attributable to the presence of corrosion-inducing gases and/or an increase in water concentration from 5% to 100%. Because the corrosion rate clearly increased with time, the mass loss also did so gradually.

Table-2 Corrosion parameter of API -5L-Grade-X52 in crude oil with various percentage of connate/formation water after 72 hours exposure time.



S.No	Electrolyte (Different Conditions)	Weight Loss (mg)	Corrosion rate (mmpy x10 $^{-3}$)
1.	Crude oil without Corrosion Inducing Gases, Water content, Free water and Emulsified Water.	0.0012	0.46
2.	Crude oil without Water content, Free water, Emulsified Water and presence of Corrosion Inducing Gas	4.3500	16.77
3.	Crude oil with 5 %, Free water	3.9330	15.16
4.	Crude oil with 10 %, Free water.	4.6000	17.73
5.	Crude oil with 25 %, Free water.	2.7667	10.67
6.	Crude oil with 50 %, Free water.	2.6000	10.02
7.	Crude oil with 75 %, Free water.	6.2000	23.90
8.	100 %, free water	11.5667	44.59

Based on corrosion investigations that measured weight loss, Table 2 shows that the corrosion rate of API 5L Grade X52 rose from 0.46 x 103 mmpy to 44.59 x 103 mmpy after 72 hours of exposure to varying concentrations of water in crude oil. Nevertheless, the creation of a primary layer on the oil pipe surface, which may itself impede further dissolution, causes the corrosion rate to slow down when compared to 24 hours of exposure time. The film generated by the crude oil solution acts as a corrosion inhibitor and helps to screen the pin holes on the inner pipe line surface. Corrosion may originate from the presence of formation water and dissolved gases that induce corrosion in the crude oil industry. The salinity of formation water is three times that of regular sea water.

Table 3 demonstrates that the corrosion rate for 120 hours of exposure time increases with the proportion of water from 0% to 100%, going from a low of 0.02 x 10-3 mmpy to a high of 69.01 x 10-3 mmpy under various circumstances of crude oil.

Table-3 Corrosion parameter of API -5L-Grade-X52 in after 120 hours exposure time.

S.No	Electrolyte (Different Condition)	Weight Loss (mg)	Corrosion rate (mmpy x10 $^{-3}$)
1.	Crude oil without Corrosion Inducing Gases, Water content,Free water and Emulsified Water.	0.0000	0.03
2.	Crude oil without Water content, Free water and Emulsified Water.	2.04	4.23
3.	Crude oil with 5 %, Free water	0.72	1.45
4.	Crude oil with 10 %, Free water.	3.41	8.23
5.	Crude oil with 25 %, Free water.	4.128	9.45
6.	Crude oil with 50 %, Free water.	3.25	8.47
7.	Crude oil with 75 %, Free water.	7.41	17.25
8.	100 %, free water	29.11	61.45

After 170 hours of exposure, the corrosion parameters of API -5L-Garde-X52 are shown in Table 4. Corrosion rates were found to rise from 0.52 x 103 mmpy to 49.29 x 103 mmpy over a wide range of crude oil conditions when the water content was varied from 0% to 100%..

Table-4 Corrosion parameter of API -5L-Grade-X52 in crude oil with various percentage of connate/formation water after 170 hours exposure time.

S.No	Electrolyte (Different Conditions)	Weight Loss (mg)	Corrosion rate (mmpy x10 $^{-3}$)
1.	Crude oil without Corrosion Inducing Gases, Water content, Free water and Emulsified Water.	0.023	0.22
2.	Crude oil without Water content, Free water, Emulsified Water and presence of Corrosion Inducing Gas	1.65	2.33
3.	Crude oil with 5 %, Free water	3.0096	6.45
4.	Crude oil with 10 %, Free water.	5.2700	8.66
5.	Crude oil with 25 %, Free water.	3.8600	6.48
6.	Crude oil with 50 %, Free water.	6.250	9.56
7.	Crude oil with 75 %, Free water.	9.728	14.16
8.	100 %, free water	29.562	48.19

Table 5 displays the corrosion characteristics of API-5L-Grade-X-52 after 230 hours of exposure under various situations. Corrosion rates were found to rise from 1.07 x 103 mmpy to 80.42 x 103 mmpy over a range of crude oil conditions and water contents (0–100%)..

Table-5 Corrosion parameter of API -5L-Grade-X52 in crude oil with various percentage of connate/formation water after 230 hours exposure time.

S.No	Electrolyte (Different Conditions)	Weight Loss (mg)	Corrosion rate (mmpy x10 $^{-3}$)
1.	Crude oil without Corrosion Inducing Gases, Water content, Free water and Emulsified Water.	0.0088	1.45
2.	Crude oil without Water content, Free water, Emulsified Water and presence of Corrosion Inducing Gas	3.54	4.01
3.	Crude oil with 5 %, Free water	2.0400	2.14
4.	Crude oil with 10 %, Free water.	4.4000	5.11
5.	Crude oil with 25 %, Free water.	4.6700	5.34
6.	Crude oil with 50 %, Free water.	8.5800	9.45
7.	Crude oil with 75 %, Free water.	11.1200	11.40
8.	100 %, free water	68.5223	78.42

Challenges in pipelines design

Meeting the design and operating criteria, often stated in codes and standards, is difficult for piping procedures, especially in the oil and gas sector. For instance, it is well knowledge that pipeline engineers have serious difficulties when it comes to repairing pipes that have leaked or ruptured [7],[11-14]. Offshore or subterranean pipes might raise the already high cost of maintaining a pipeline. Yet, joining procedures are required to interconnect thousands of kilometers of pipes in large networks. Consequently, pipeline joining is a major concern in pipeline development. The breakdown of the pipeline was also clearly managed by the kind and position of the joints [15]. This is because joints are seen as crucial by designers (i.e., stress risers). In addition, catastrophic pipeline failures may be traced back to the stress concentration caused by the sudden change in the geometry of the pipeline at elbows and T-joints. In addition to the difficulty in linking the pipes together, corrosion poses a serious threat to the pipeline's ability to withstand pressure, compromises its structural integrity, and shortens its useful life. Additionally, if these aspects are not properly accounted for in the design, they will cause an unscheduled shutdown. As was previously noted, corrosion and joining are two major issues that may develop in pipelines and are both extensively covered here.

Effect of welding on pipes pressure behavior

Flange connection welds, buckling arrestors, and circumferential butt welds all contribute to stress concentrations in pipelines. Pipelines are subject to stress concentrations from repeated variations in internal pressure, such as during the start-up and shut-down of activities or during gas transit.

Combined axial and radial internal pressure

Pipes have been tested for KF with combination radial as well as axial internal pressure by affixing hoses to the intake and outflow at both ends using a spherical device. The data shows that the pipe went through the cyclic pressure stage after 16 seconds after filling and failed following five seconds at 100 bar internal pressure. The leak is to blame for the breakdown. At the exact same time, the break in the pipe is just at the connection point itself. This indicates that the failure occurred because the layer touching the pipe did not have enough resin. Pipes that have been linked together need a fastening that can hold the pipe in place at both ends while limiting the application of force in any direction other than along its radial axis.

Conclusion

Results from a study comparing the compressive stress capability of composite material in pipe joining to that of welding, a process with several limitations owing to its lack of features, were shown to favor the fiber composite. Kevlar and fibreglass composites have been utilized to join aluminum pipes. The bending test's top-performing joint variants were put through an internal pressure evaluation. As compared to the conventional welding procedure, fiber composites were shown to significantly enhance the compressive stress capacity of the connected pipes. Nevertheless, in the instance of fiber composites joining, leakage from of the joint edges was found during an internal pressure test, even though there was no obvious deformation with in joint structure or the pipe bulk. It was decided to conduct a corrosion test. The results showed that FRP joining techniques provided superior corrosion protection compared to welded and unjoined pipes. Our research suggests that Composites provide hope for the future of pipeline joining in the fight against pipeline corrosion.

References

1. Tao, L.-J., Zhang, Y., Zhao, X., Bian, J., Chen, X.-H., An, S., & Han, X.-C. (2021). Group Effect of Pipe Jacking in Silty Sand. Journal of Geotechnical and Geoenvironmental Engineering, 147(11). https://doi.org/10.1061/(asce)gt.1943-5606.0002613
2. Raj Singh, P., Kanvinde, A., & Narasimhan, S. (2021). Assessing the Fracture Risk of Corroded Cast-Iron Pipes in Expansive Soils. Journal of Pipeline Systems Engineering and Practice, 12(4). https://doi.org/10.1061/(asce)ps.1949-1204.0000582
3. Jun, H. J., Park, J. K., & Bae, C. H. (2020). Factors Affecting Steel Water-Transmission Pipe Failure and Pipe-Failure Mechanisms. Journal of Environmental Engineering, 146(6). https://doi.org/10.1061/(asce)ee.1943-7870.0001692
4. Tee, K. F., & Pesinis, K. (2020). Bayesian Updating and Reliability Analysis for High-pH Stress Corrosion Cracking in Gas Pipelines. Journal of Engineering Mechanics, 146(7), 04020074. https://doi.org/10.1061/(asce)em.1943-7889.0001803
5. Mazumder, R. K., Salman, A. M., Li, Y., & Yu, X. (2018). Performance Evaluation of Water Distribution Systems and Asset Management. Journal of Infrastructure Systems, 24(3), 03118001. https://doi.org/10.1061/(asce)is.1943-555x.0000426
6. Wang, W., Robert, D., Zhou, A., & Li, C.-Q. (2018). Factors Affecting Corrosion of Buried Cast Iron Pipes. Journal of Materials in Civil Engineering, 30(11). https://doi.org/10.1061/(asce)mt.1943-5533.0002461

7. Ghaednia, H., & Das, S. (2018). Structural Performance of Oil and Gas Pipe with Dent Defect. Journal of Pipeline Systems Engineering and Practice, 9(1). https://doi.org/10.1061/(asce)ps.1949-1204.0000301
8. Jafari, N. H., Stark, T. D., & Thalhamer, T. (2017). Progression of Elevated Temperatures in Municipal Solid Waste Landfills. Journal of Geotechnical and Geoenvironmental Engineering, 143(8). https://doi.org/10.1061/(asce)gt.1943-5606.0001683
9. Zhao, H., & Andrawes, B. (2017). Mechanical Properties of NiTiNb Shape Memory Alloy Subjected to a Harsh Corrosive Environment. Journal of Materials in Civil Engineering, 29(3). https://doi.org/10.1061/(asce)mt.1943-5533.0001725
10. Hadi, M. N. S., Hasan, H. A., & Sheikh, M. N. (2017). Experimental Investigation of Circular High-Strength Concrete Columns Reinforced with Glass Fiber-Reinforced Polymer Bars and Helices under Different Loading Conditions. Journal of Composites for Construction, 21(4). https://doi.org/10.1061/(asce)cc.1943-5614.0000784
11. Alberti, M. G., Enfedaque, A., Gálvez, J. C., & Pinillos, L. (2017). Structural Cast-in-Place Application of Polyolefin Fiber–Reinforced Concrete in a Water Pipeline Supporting Elements. Journal of Pipeline Systems Engineering and Practice, 8(4). https://doi.org/10.1061/(asce)ps.1949-1204.0000274
12. Wang, F., Han, J., Corey, R., Parsons, R. L., & Sun, X. (2017). Numerical Modeling of Installation of Steel-Reinforced High-Density Polyethylene Pipes in Soil. Journal of Geotechnical and Geoenvironmental Engineering, 143(11). https://doi.org/10.1061/(asce)gt.1943-5606.0001784
13. St. Clair, A. M., & Sinha, S. (2014). Development of a Standard Data Structure for Predicting the Remaining Physical Life and Consequence of Failure of Water Pipes. Journal of Performance of Constructed Facilities, 28(1), 191–203. https://doi.org/10.1061/(asce)cf.1943-5509.0000384
14. Rajani, B., & Abdel-Akher, A. (2013). Performance of Cast-Iron-Pipe Bell-Spigot Joints Subjected to Overburden Pressure and Ground Movement. Journal of Pipeline Systems Engineering and Practice, 4(2), 98–114. https://doi.org/10.1061/(asce)ps.1949-1204.0000125