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A Review on Evaluating the Optimization of Fibre Reinforced Polymer for Compound/Repair Clamp on Leaked Piping System using Computational Simulation

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ABSTRACT

Most industries around world depend on pipelines to transfer millions of gallons of flammable and non-flammable materials. However, this pipeline system has been affected by exposure, which may cause the entire system to fail due to corrosion-based issues. Repair clamps have been used to prevent total failure from happening in a continuous run. However, current design of repair clamp is consisting of metal whereby long usage on corroded pipe could be much more affected. The weight factor will be affecting the fluid flow and the structure of pipe when used in long run. Therefore, in this research, new design for the repair clamp will be done and the material will be change to fibre reinforced polymer (FRP). The new design with FRP will be undergo various stimulation on SolidWorks to compare the properties of clamp and the effect on the affected pipe. Since the FRP material properties has been proven to be more stronger and sustainable compare steel that has been using currently, it will be much more effective to use. As a result, the new design will be much more sustain than the old metal repair clamp. Since the new clamp is lightweight, the weight no longer will affect the corroded pipe internally and externally. Moreover, in this research some of the current repair clamp parts has been reduced and changed to compromise with the usage of the FRP.

1. Introduction

The current working culture prioritizes sustainable technologies for effective and competitive production using advanced systems, software, machines, tools, and infrastructure systems. Critical Infrastructure (CI) is the most important infrastructural facility, and strategic infrastructures (SIs) [1] are the most critical of them. Pipeline systems are the most common and essential element of CI, and they are used for domestic purposes as well as in oil and gas production, nuclear and cogeneration power plant production, ships, and aircraft control systems.

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Pipeline systems used in various industries, such as oil and gas, consist of pipes, pumps, compressors, and other facilities, and their exposure is decided based on their industrial usage. However, exposure can lead to pipeline failure, which is one of the biggest backlogs to the industry, and safety is given the highest priority in these critical sectors due to the high-risk exposure. The combination of design, material, and operating practices always lowers the chances of pipe failure, and natural occurrences and exposure to critical elements also contribute to pipeline system failure [2]. To eliminate such failures, pipeline structure is given the highest level of priority and maintenance to maintain continuous product flow. In the oil and gas industry, corrosion is a significant problem due to the constant flow of fluids through pipes and service environments. Corrosion can cause pipelines to break down early, leak, and lead to production shutdowns in the concern of OSH which led to a lot of loss [3].

Pipeline failures can have severe consequences and that repairing them as quickly as possible is essential. So, various techniques, such as cutting and welding, wrapping, and clamping, have been introduced to solve pipeline corrosion-based problems. Clamping has become a famous solution for these problems, especially using metal clamps, which are effective for high-pressure pipelines. Metal clamps are tightly clamped at the damaged area using bolts and nuts, and resin covers the damaged area. However, metal clamps have some problems whereby it may affect the corroded pipeline on a long-term usage with its weight factor. Meanwhile, the composite materials, such as fibre reinforced polymer (FRP), have become the main choice for metal replacement due to their properties, such as being more corrosion-resistant, lightweight, and having similar or better properties than metals.[4] A study has been conducted to determine if using FRP is a better replacement for the existing metal clamp used in pipeline problems. This study aims to analyse the properties of repair clamp using FRP and its performance using SolidWorks software. The study is expected to provide a better breakthrough in the design and the material usage of repair clamps, paving the way for new clamp designs using composite materials [3].

1.1 Defect on Pipeline

It is essential to know about the defect that has been happening on the pipeline to analyse the usage of repair clamp. Each type of defect requires different types of clamps and clamping methods. The corrosion-based defects that happening on the pipe are the fundamental of its total failure of usage and have tendency to close down the entire safety system since the pipes in the industries always carrying some vary of fluids that could be flammable or not.

Pipe system (Figure 1) that are buried and often located in areas of construction activity are susceptible to defects and anomalies. When the presence of defect is detected, normally the pipe system is restored to its original design configuration through repairs [5]. Since the repair clamping method is applied for external surface of the pipe system, only the external defects are considered in this case. One of the external defects are the external corrosion and the pipe leakages [6]. The definition of corrosion is the deterioration of a material because of its interaction with its surroundings and can occur at any point or at any time during petroleum and natural gas processing. All material that has metal element tending to corrode if we place them in an environment that causes that particular material to deteriorate [7]. External environment is the basis of the external corrosion occurrence. External pipe surface interaction with soil, air or water are acknowledged as the external environment. In general, corrosion is categorized either general corrosion or localized (pitting) corrosion [8].

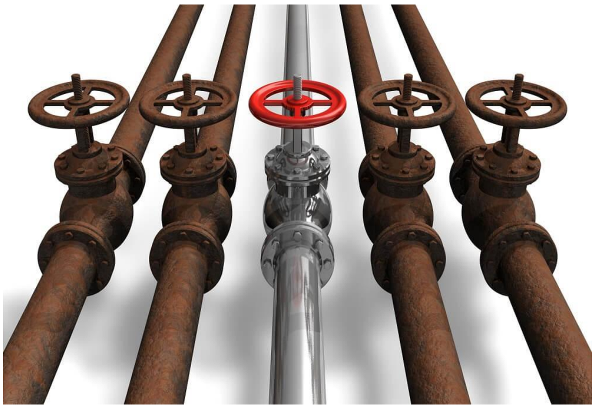


Fig. 1. Difference between new and corrode pipe

There actually various type of corrosion defects has been identified. Corrosion varies towards its environmental exposure and the contributing factors. It is very essential to know all type of corrosion if we need to prevent it. Specifically, there are 16 types of corrosions that are involved in pipeline failure. The list of various defect types are as follows [9,10]:

i. Galvanic Corrosion
ii. Microbiologically Induced Corrosion
iii. AC Corrosion
iv. Differential Soils
v. Differential Aeration
vi. Cracking
vii. Defect-Free Pipe
viii. Corrosion
ix. Gouges
x. Plain Dents
xi. Kinked Dents
xii. Smooth Dents on Welds
xiii. Smooth Dents Containing Gouges
xiv. Smooth Dents Containing Other Types of Defects
xv. Manufacturing Defects in The Pipe Body
xvi. Girth Weld Defects
xvii. Seam Weld Defects Cracking
xviii. Environmental Cracking

As mentioned earlier metal loss due to corrosion may occur internally or externally on the pipe surfaces, base material, seam weld or in the girth weld [11]. As this corrosion lead to metal loss substantially it leads leakages and failure in mechanical strength which may lead to destruction. Therefore, we need to know all type of defects so we could take the correct action to prevent any wreaking havoc.

1.2 Other Methods to Prevent Affected Pipeline from Total Failure

There are variety of methods to repair pipeline defects, and the methods always chosen depends on material pipe, load exerted, type of damage, mixture of parameters, and the application of pipe.

1.2.1 Compound box

Compound box technique provides a custom-made box for each defect, which is filled with compound sealing. The epoxy compound is injected into the valves surrounding the box to escape trapped air, making the repair system more efficient. This method is safe way, and able to solve the pipeline problems temporarily, provided having the good compatibility on the pipe [12]. Figure 2 illustrates the flange joints which shows the compound is injected through valve to cure.

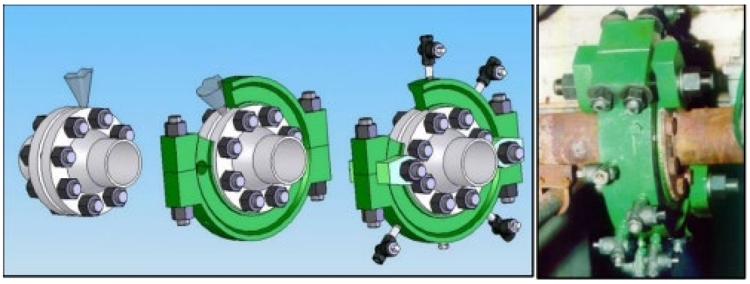


Fig. 2. Flange joins to section of pipe, where thereafter the compound is injected through valve to cure [13]

1.2.2 Wrapping

Laminated tape is a type of pipe repairing system technique that consists of two layers of butyl rubber and polyethylene (Figure 3). A laminated tape consists of two layers as following where Inner layer of butyl rubber to bond to the primer, referred to as “Adhesive” while Outer layer of polyethylene referred to as "Backing”. The laminated plastic tape shall have a backing of stabilized polyethylene and a primer activated adhesive mass of butyl rubber It is resistant to bacterial, fungi, vegetable and salt solutions, and is suitable for line travel and shop coating [14].

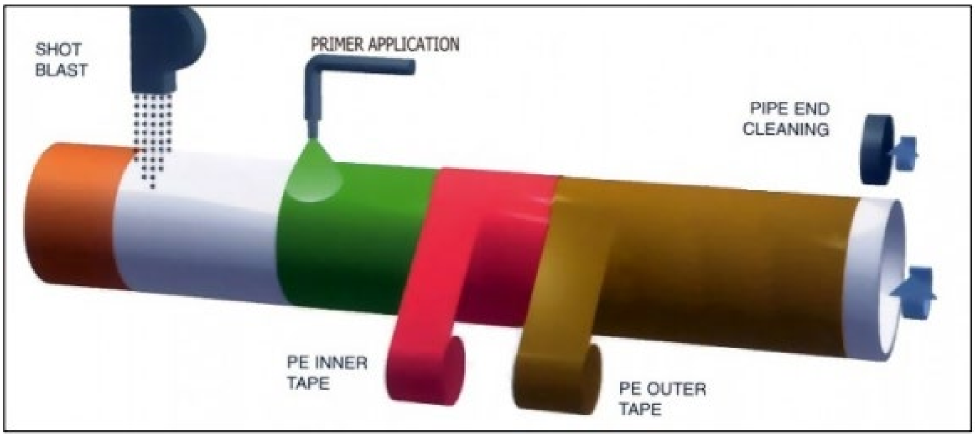


Fig. 3. Wrapping method [15]

1.2.3 Slip lining

Slip Lining (Figure 4) is a method of repairing pipes with tubes injected within the pipe. It is only used for low pressure pipes and does not allow repairing process when the pipes are in service. It involves injecting a tube of polyester into two wells, turning it inside out, pushing through the pipe, or bursting the old pipe and relining with new pipe [16].

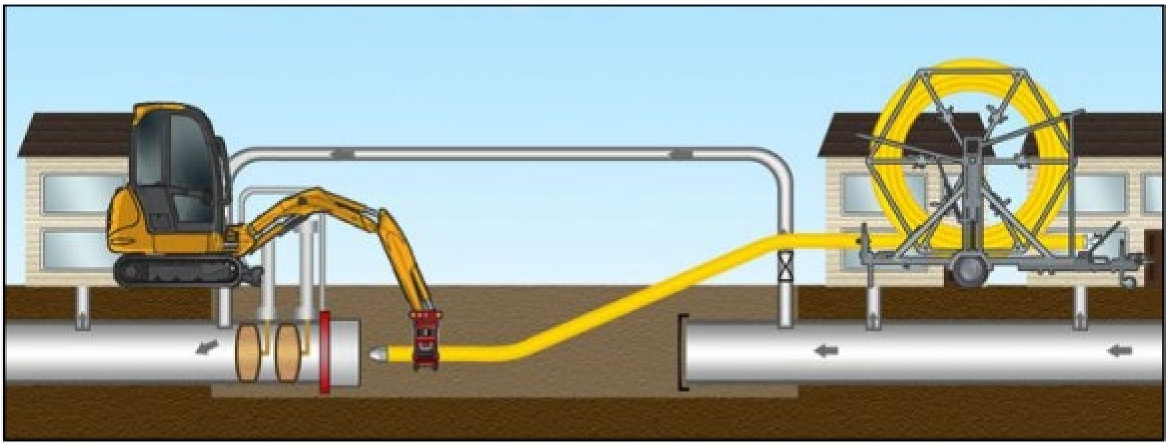


Fig. 4. Slip lining process [17]

So, to enhance the usage of the repair clamp by replacing it with FRP we should know the defect first. In order to achieve the objective of the research which is longs the life span of the corroded pipe by changing the material of the clamp will be achieve through the finest analysis and stimulation by the SolidWorks.

2. Repair Clamp

Repair clamps (Figure 5) are a common item in industrial settings for permanent and temporary pipe repair. They are available in a wide range of types and sizes, and they are frequently the first choice for industrial pipe repair since they can alleviate the problem quickly and effectively, minimizing downtime. Depending on the individual requirements of the repair project, several repair clamps and coupling pipe fittings may be used. The proper type of clamp must be utilized to ensure the installation's optimal integrity.

Derrick, Virgil H., in 1915 is the man who invented the pipe clamp with the purpose of repairing and coupling. Since this research focuses on repair clamps as temporary repairs for various type of pipe defect. Repair clamps are a common means of repairing pipelines with leaking defects [3]. Repair clamps are an ideal solution for preventing leaks and restoring network integrity if they occur. Pipe repair clamps, in their most basic form, are necessary components that cover a defect on the pipe with their bodies and, via mechanical seals, return the parameter to its initial value. It attaches itself to the line and block leakage within the defective part. Repair clamps can be used for short-term or long-term fixes.

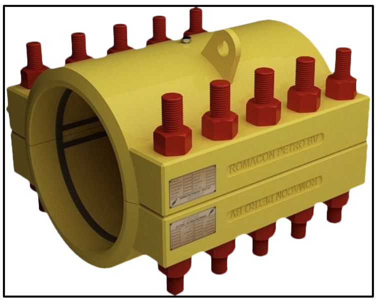


Fig. 5. The repair clamp [18]

2.1 Function

A pipeline repair clamp is a type of mechanical device designed to repair a damaged section of a pipeline quickly and temporarily. It is used to seal leaks or fractures in a pipe and prevent the flow of fluid or gas from escaping.

The primary function of a pipeline repair clamp is to provide a quick and efficient solution to prevent further damage to the pipeline while repairs are being made. The clamp is typically made of metal or other durable materials and is designed to fit tightly around the damaged section of the pipe, creating a seal that prevents further leakage. Pipeline repair clamps can be used in a variety of applications, including oil and gas pipelines, water pipelines, and sewage pipelines. They are also commonly used in emergency situations where a pipeline has been damaged or ruptured, such as natural disasters or accidents [19].

Overall, the function of a pipeline repair clamp is to provide a temporary solution that allows repairs to be made without interrupting the flow of fluid or gas through the pipeline, minimizing the risk of further damage, and reducing downtime.

2.2 Type of Repair Clamp

Numerous types of repair clamp have been using for solving the defects happening on the pipe using in the oil and gas line. Each type of repair clamp's usage will be varied according to the type of damage to the pipe, the scope of leak and the condition of pipe surface. Those factor consideration is main factor to choose the correct type of clamp according to its problem. There are different types of pipeline repair clamps available in the market, some of which are [20].

2.2.1 Full circumferential clamp

This is the most used type of clamp and provides a complete 360-degree seal around the pipe (Figure 6). It is typically used for repairing small leaks or breaks on pipes.

Fig. 6. Full circumferential clamp [21]

2.2.2 Split repair clamp

This type of clamp is designed for use on pipelines that cannot be shut down (Figure 7). It consists of two halves that are bolted together around the damaged section of the pipe, allowing for a quick and easy repair.

Fig. 7. Split repair clamp [18]

2.2.3 Bell joint leak clamp

This type of clamp is designed for repairing leaks on bell-and-spigot joints (Figure 8). It is typically used on water and sewer pipelines.

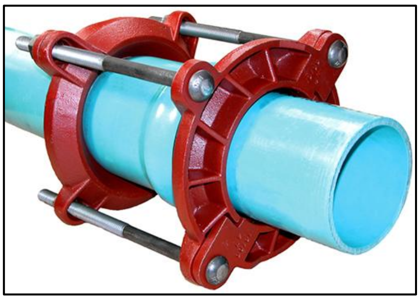


Fig. 8. Bell joint leak clamp [22]

2.2.4 Flange leak clamp

This type of clamp is used to repair leaks on flanged connections (Figure 9). It consists of a two-piece design that can be quickly and easily installed around the damaged flange.

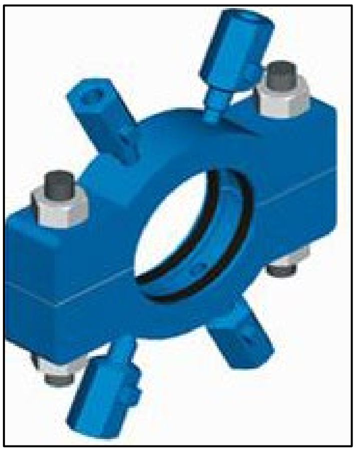


Fig. 9. Flange leak clamp [13]

2.2.5 Tapping sleeve and valve

This type of clamp is used to make a branch connection on an existing pipeline (Figure 10). It consists of a sleeve that is bolted onto the pipe, and a valve that is installed on the sleeve to control the flow of fluid through the new branch.

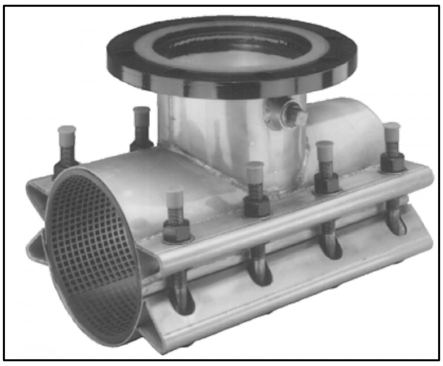
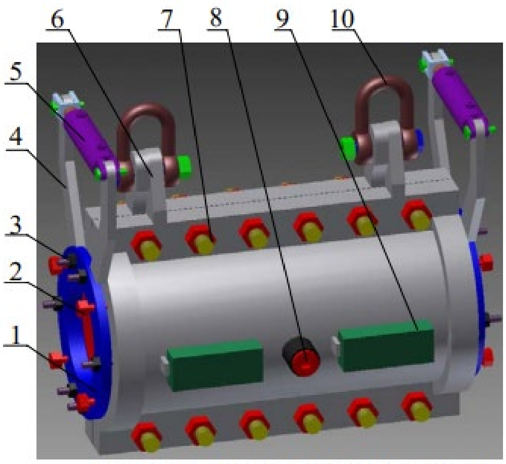


Fig. 10. Tapping sleeve and valve [23]

2.3 Design of Existing Clamp
2.3.1 Design of overall structure (split repair clamp)

The overall structural of driverless full structure permanent pipeline repair clamp is shown as Figure 11 and Figure 12, which is composed of the clamp body, the master bolts, hydraulic cylinders, compressed bowl, tension slips, tighten flange, flange bolts, drilling hole, circumferential sealing module, axial seal, sacrificial anode. The sealing performance of the clamp is the primary performance of the clamp device. The circumferential and longitudinal seals use double sealed, increasing the reliability of the seal of the clamp.



Structural of the clamp-I: 1- Tighten flange; 2- The sealing bolts; 3- Flange bolts; 4- Opening and closing hydraulic auxiliary arm; 5-Hydraulic cylinders; 6- Istallation rings; 7- The master bolts; 8- Drilling hole ; 9- Sacrificial anodes; 10- Rings.

Fig. 11. Basic parts of a clamp [18]

2.3.2 Design of the clamp body

The clamp body is composed mainly of the two semi massive structures. The installation rings, opening and closing hydraulic auxiliary arm, hydraulic cylinder mounts, tighten the bolt hole, flange base and other features are designed in the clamp body. The installation rings are used to lift the clamp in the right place easily when the subsea installation work is conducted. The installation rings, opening and closing hydraulic auxiliary arm, hydraulic cylinder mounts can facilitate opening and closing movements of the clamp when the underwater installation work is conducted, which is more conducive to the underwater installation environment. When the main bolts through the tighten bolt holes are tightened, the clamp is closed, then the longitudinal seals are achieved. The flange base is used to connect with tighten flange [18].

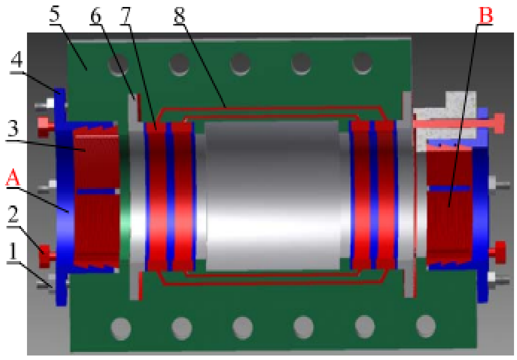


Figure 2. Structural of the clam-II: 1- Flange bolts; 2- The sealing bolts; 3- Tension slips; 4- Tighten flange; 5- The clamp body; 6- Compressed bowl; 7- Circumferential sealing module; 8- Axial seal.

Fig. 12. Design of clamp body [18]

2.4 Material Used

Materials:

i. Stainless Steel: It is the most common material used for pipeline repair clamps because of its corrosion resistance and strength. It is suitable for a wide range of operating conditions and can withstand high pressures and temperatures.
ii. Carbon Steel: It is also commonly used for pipeline repair clamps because of its strength and durability. However, it is prone to corrosion, so it is usually coated with a protective layer.
iii. Ductile Iron: It is used for pipeline repair clamps for lower-pressure applications. It is also coated with a protective layer to prevent corrosion.

However, the material properties of the clamp body are the same as or higher than the pipe material. ASTM A105 forging for 12 in NPS and larger, ASTM A516 Gr. 70 pressure vessel plate for 10” NPS and smaller are used in other countries. By comparing the comprehensive performance of the above two materials with Q235R, the Q235R is chosen as the clamp body material finally, the diameter size of the pipeline can be ignored in the design of the clamp [24].

The material of traditional repair clamp will be replaced with the fibre reinforced polymer (FRP) to enhance the usage of the repair clamp. Since the usage of metal repair clamp is affecting the corroded pipeline in a long duration, this research proposed to prove that usage FRP will be increase the life span of pipe even though its corroded. The FRP repair composite will be stimulated and analysed under various analysis using the aid of CAE and CAD software which is SolidWorks [25]. This research could be a milestone for the usage composite material in oil and gas industry. People will be more aware of the advantage of using composite materials for repair systems.

3. Analysis

The previous research that related on this research has been analysed and proofing the outcome of this research through the aid of the previous researches.

From the research of failure analysis and design of grouted fibre-composite repair system for corroded steel pipes by Shamsuddoha, M., Manalo, A., Aravinthan, T., Islam, M., & Djukic, L. shows that grouted fibre-reinforced composite stand-off sleeve repair is a lightweight and easily deployable repair system for steel pipelines with localized metal loss. The effectiveness of this type of repair system is dependent on the load transfer through the grout layer, which is weaker than neighbouring components and susceptible to failure due to stresses developed from applied internal pressure. In this study, three-dimensional (3D) Finite Element Analyses (FEA) of a full-scale pipe with different levels of metal loss were implemented to evaluate the failure behaviour and capacity of grouted composite repair system. Steel pipes with a localized defect ranging from 20% to 80% metal loss and repaired using two infill grout systems reinforced with carbon and glass sleeves of different thicknesses were considered. The results indicated that the performance of the repair system is governed by the tensile cracking of the infill grout. A thicker sleeve and higher tensile strength grout deliver higher pipe capacity in the repair system. On the other hand, a high modulus grout provides a more effective load transfer from steel to sleeve. Using a high tensile strength grout, the composite repair system can restore the capacity of the steel pipe with defect up to about 70% metal loss [26].

Rather than that, from the assessment of composite repair system in offshore platform for corroded circumferential welds in super duplex steel pipe by Barros, S., Budhe, S., Banea, M., Rohen, N., Sampaio, E., Perrut, V., & Lana, L. states that the main aim of the study is to assess the effectiveness of a composite repair system in severely corroded circumferential welds in super duplex stainless steel pipes as a preventive measure against the premature corrosion damage at the welds. Artificial defects were fabricated on the super duplex steel tube to reproduce the localized corrosion damage defects found in real welded joints. Three kinds of through thickness defects were considered: 25%, 50% and 96% of the perimeter of the pipe. The performance of the repaired pipe was assessed by hydrostatic tests as per ISO 24817 standard. The results showed that the composite repair system can sustain the designed failure pressure even for the pipe damaged with through-wall defect up to 96% of the perimeter of the pipe. Hence, the composite repair system can be used as a preliminary tool to protect the unexpected or premature failure at the welds and maintain an adequate level of mechanical strength for a given operating pressure. This composite repair system can assure that the pipe will not leak until a planned maintenance of the line. Nevertheless, further work is still desirable to improve confidence in the long-term performance of bonded composite [27].

Moreover, the Analysis of ultimate pressure of corroded subsea pipe repaired with composite considering temperature and material degradation by Xin, J., Zhang, Y., Zhong, C., Cheng, Z., & Jia, Z. (2020) also states the corroded subsea pipe repaired with composite material is more and more used because of its low cost, simple process and short time, but the repair effect will be affected by factors such as temperature and material degradation. To study the law of the effect, the finite element method is used to analyse ultimate loads on repaired pipe by considering the factors of temperature and material degradation. The results show that the ultimate yielding and bursting pressure decreases with the increase in temperature for both the defective pipe and repaired pipe under temperature and internal pressure. The ultimate pressures are larger when both ends of the pipe are fixed compared with one end is free, but they also decrease faster as the temperature increases. Experiments show that elastic modulus and glass transition temperature of composite will decrease when exposed to prolonged seawater and high temperature. The degradation of composite repair layer performance has a great effect on the ultimate pressure of pipe, and the failure of the repair area will be caused under long-time harsh environment. In this paper, the design repair thickness of composite is obtained, which could improve the repair efficiency of corroded pipes and reduce cost as well [28].

Every analysis that based on the prevention method of total loss of pipeline has been stating the usage of fibre reinforced polymer (FRP) as the replacement for the metal on the compound/ repair clamp is showing enormous advantage that's proofing the objective of this research will reach success which is the increase the lifespan of the corroded pipeline by using this FRP repair clamp which may prevent a lot negative effect.

4. Conclusions

Through this research we can obtain a lightweight composite compound clamp which we could replace the existing metal compound clamp. The new compound/ repair clamp could be much more efficient for solving problems related to corrosion-based problems. The new compound clamping mechanism with the optimization of composite material such as fibre reinforced polymer will be evaluated using the SolidWorks simulation. The new mechanism could be much easier to optimize than the existing ones. Moreover, this design could be one of the benchmarks for starting composite material usage in pipe defect repairing. It is because the new clamp could have much more extended lifetime than the existing and it will be much more welcomed by the industries because its material and mechanism will help the industries to save more money. Moreover, the new clamp has a higher commercial potential if the research moves to the next level, which is fabrication.

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