Rehabilitation of corroded steel pipelines with epoxy repair systems

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Abstract

The rehabilitation of corroded pipelines with epoxy repair systems is now becoming a well accepted practice in the oil transportation industry. Laboratory hydrostatic burst tests and field practice of several years have shown that these repairs may be effective even for pipelines with trespassing corrosion defects. This research paper deals with laboratory tests carried out to validate epoxy repair systems applied in through-the-thickness corrosion defects in offshore produced water pipelines. The experimental tests aim to analyze the performance of different epoxy resins in real offshore platform repair situation. Although the operation pressure of produced water pipelines is not very high, the water temperature is between 60^oC to 80^oC, which can be a major shortcoming for the use of polymeric material as repair systems. Initial verification hydrostatic tests were performed to verify the repair efficiency, i.e. no leakage occurs. After this initial task temperature and pressure were applied to perform real produced water situation. Tests results showed that temperature is an important issue to polymeric materials applied to steel pipelines.

Keywords: polymer testing, epoxy repair, hydrostatic tests, offshore pipelines

1 Introduction

The fast recent increase of the petroleum and natural gas production associated to a great energetic demand and primary resource provokes a significant increment in the national consumption of oil (gasoline, diesel. naphtha. etc) and gas.

As well as in other parts of the world, the discovery of relevant lied of hydrocarbonets in the Brazilian offshore coast made Brazilian petroleum company invest more and more in the installation of petroleum

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extraction marine platforms. The exploration of these deposits constitutes high proportion business, as much as financial investment as return potential of the investment, regarding the production volumes involved and the load of the facilities that are necessary.

The petroleum as found in the nature is actually a mixture, basically composed of oil, gas and water. The platform equipment make possible the petroleum elevation, separate oil-gas-water, export the oil to the ship, treat the produced water for disposal, reinjection or platform onboard utilization.

During the process of petroleum production it is common to co-produce water and gas. The water of associated formation can reach values of 50% of the produced volume or even approximating 100% in the end of the productive life of the wells. The discard or even the reinjection of the co-produced water is allowed only after the removal of the oil and solids in suspension at acceptable levels [1].

Produced water, which contains various chemicals such as heavy metals, polynuclear aromatic hydrocarbon, and radionuclides, is one of the most significant wastewater discharges in the offshore oil industry.

Figure 1: Corrosion damage in produced water pipelines.

The damages derived from corrosion process in industrial installations produce economical losses very important. For gas and petroleum industry, the corrosion is responsible for 33% of the cases [2].

The repair and reinforcement of existing structures has received a significant emphasis over the past few years due to corrosion and infrastructure aging. After some time in service, steel pipeline may be damaged, so they may be in need of repair due to the loss of carrying capacity. Alternatively, existing structures may need to have their resistance or stiffness upgraded to withstand an increased load demand or to eliminate structural design or construction deficiencies.

The technique for repairing existing structures was initiated with the development of strong epoxy adhesives in the late sixties and early seventies. The additional bonded reinforcement enhances the

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performance under service loads by reducing deflections and cracking, and increases the ultimate strength.

The debonding mechanism is driven by stress concentration at the laminate end or in the vicinity of existing cracks, and is generally initiated from within the substrate between the adhesive bonded and the internal damage area. Therefore, the reliability of the epoxy reinforcement depends mainly on a proper stress transfer from adhesive layer through the interface to the damaged area.

In this joint research project repair of trespassing defects with epoxy systems were done to validate those applications that are being performed in offshore platform.

2 Materials

The aim of this work is study the effectiveness of epoxy resins used in pipeline repair of steel pipes. Hence, tubular specimens were provided with artificial defects, simulating a localized through-the-thickness corrosion. The “defect” is a circular hole with 10mm diameter. Such defects were made severe on purpose in order to investigate how far epoxy repair systems can reach.

The API 5L grade B seamless steel pipe, normally used in offshore platform for produced water, was used to be repaired with an epoxy emergency rapid curing system. This type of pipe has a chemical composition according to table 1.

Table 1: Chemical Composition of API 5l grade B Steel

$C_{máx}$	$Mn_{máx}$	$P_{máx}$	$S_{máx}$
0,27	1,15	0,030	0,030

The steel pipe tested has the following dimension, see table 2

The steel pipes had been threading internally with thread of normal step, in one of the extremities. In the other extremity exist a welded flange with 76.2 mm of diameter and 12.7 mm of wall thickness, as it is shown in figure 2.

Three different epoxy repair systems were analyzed. The first one (System A) was a rapid setting, emergency stick easy to carry and use. The product solidifies in 5 to 10 minutes. NSF-approved for drinking water contact. Thick, clay-like consistency allows it to be mixed in worker’s hands (with glove protection) and can be applied to active leaks. Ideal for leak repair on tanks and pipes as well as for other emergency applications. Seals up to 0,28 kg/cm^2 (4 psi) of head on active leaks and 7 kg/cm^2 (100 psi) after-cure. The second one (System B) was an emergency repair material, polymer-based system which provides a alternative to conventional repair compounds. Based on technology that was previously available only to the aerospace industry and those at the forefront of motor vehicle design. The third one (System C) was also a polymer-based system especially developed for repair consisting of a mixture of epoxy resin and aluminium powder.

Table 2: Pipe specimen dimension

Dimension	API 5L grade B
Nominal Diameter (mm)	50.8
External Diameter (mm)	60.3
Schedule (sch)	80
Thickness (mm)	5,54
Length (mm)	1300
Defect Diameter (mm)	10

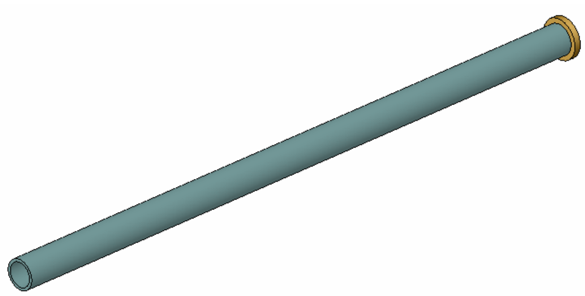

Figure 2: Specimen configuration

3 Specimens preparation

Surface treatments often involve chemicals reactions, which produce surfaces modifications on adherends, or mechanical procedures, which improve adhesion by increasing mechanical interlocking of the adhesive to the adherend. By this way, the primary objective of a surface treatment is to increase the surface energy of the adherend as much aspossible and/or improve the contact between the adhesive/adherend by increasing the contact area.

Roughness or an increase in the surface area has been shown good results in improving adhesion. Subsequently, a relationship exists between good adhesion and bond durability.

In order to obtain the previous properties, API steel pipe surface was roughened by power tool to achieve a white metal appearance and to remove some of the existing oxide layer (see figure). A final rinse with solvent was made to provide a free of oil, grease and dirt surface. After that the adhesive was mixed according to manufacture procedure and then the pipe was repaired.

Figure 3: Epoxy repair procedure

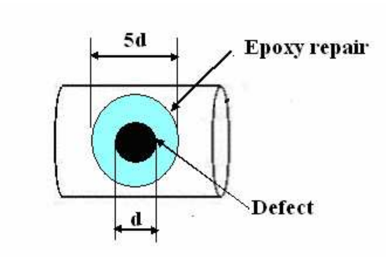

Figure 4: Epoxy repair area.

4 Experimental set-up

The present study is concerned with the analysis of the effectiveness of some epoxy repair systems in through the wall flaws in metallic pipelines caused by corrosion. The experimental set up was conceived to approximate a real repair operation, where the resin has to be applied in field conditions (which affect the quality of the resulting epoxy repair).

For the leakage experiments, five samples were used for each resin. The combination of three resin and five specimens resulted in fifteen experiments.

The repaired pipeline was then submitted to a hydrostatic test to evaluate its strength and effectiveness. The hydrostatic testing machine uses air pressure to generate hydraulic pressure. The test set-up apparatus is showed in figure 5.

The complete experimental procedure is composed of two tests. In the first test, the the water is at room temperature and the pressure is increased up to 30 kg/cm^2, pressure used in water disposal offshore platform pipeline, and left by an hour. After such procedure, if the repair don't fail brutally, the specimen is unloaded and inspected to check eventual small leaks or reinforcement rebounding.

In the second test the water temperature inside the specimen is increased until 80^{o}C at atmospheric pressure. Such temperature level was chosen in order to simulate average offshore fluid condition. After temperature stabilization, the internal pressure is increased until 30 kg/cm^2 and maintained for

Figure 5: Test Set-Up Apparatus

1 hour.

The system to control water temperature inside the specimens was especially designed for this procedure (Figure 6). Number 1 is the pressure water machine connection, 2 is the temperature control thermostat and 3 is the electrical resistance. In this test, the specimens also were inspected to check for small leaks.

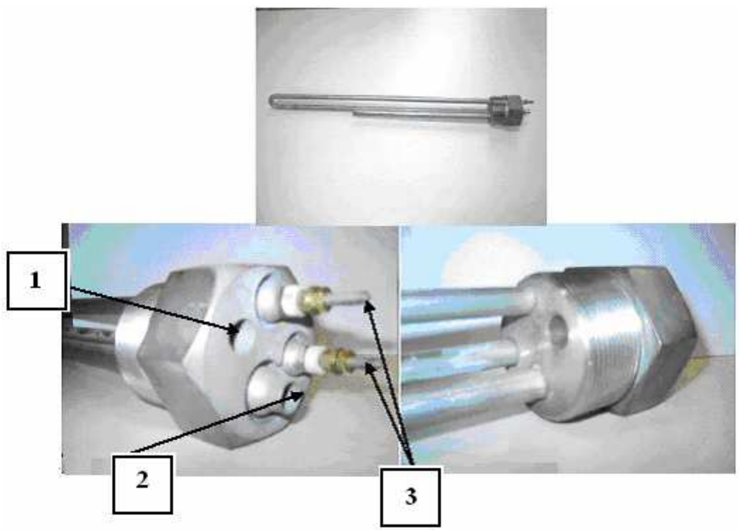

Figure 6: Detailed Temperature Control System

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5 Results

Systems A, and C supported the pressure testing with water at room temperature but system B failed during the hydrostatic pressure test. Just in the beginning of the test, small leaks were detected in system B.

In the pressure testing with water at 80^oC, System C resisted 5 cycles of loading, system A reached the temperature of 80^oC but failed during the increase of internal pressure and System B failed even before the increase water temperature. The values of the failure temperature and failure pressure can be seen in table 3 and 4 respectively for adhesive A and B.

Table 3: Epoxy Repair Systems "A" Tests Results

	Test 1: water at room temperature	Test 2	
Specimen	Failure Pressure (kg/cm^2)	Failure Temperature ($^\circ$C)	Failure Pressure (kg/cm^2)
1	-	80	8.92
2	-	80	17.64
3	-	80	16.17
4	-	80	18.35
5	-	80	14.27
Average	-	80	15.07

Table 4: Epoxy Repair Systems "B" Tests Results

	Test 1: water at room temperature	Test 2	
Specimen	Failure Pressure (kg/cm^2)	Failure Temperature ($^\circ C$)	Failure Pressure (kg/cm^2)
1	-	69	10.19
2	-	49	4.49
3	-	49	4.28
4	-	45	2.74
5	-	43	5.13
Average	-	69	5.37

Epoxy Repair System C – Resisted 5 cycles of 1 hour at 80^oC with internal pressure of 30 kg/cm^2
Figure 7 displays the epoxy repair system A before and after the tests and figure 8 shows the epoxy repair system B.

Figure 7: Epoxy Repair System A

Repair system C, displayed in figure 9, supported very well both pressure and temperature. Repair system A can support the increase of temperature but did not support the increment of hydrostatic pressure with an average of 15.07 kg/cm^2. In repair system B the adhesive did not hold the increase of temperature failing just before reaching 50 $^\circ$ C, except specimen 1 and also for low hydrostatic pressure 5.37 kg/cm^2 in average.

Figure 8: Epoxy Repair System B

Figure 9: Epoxy Repair system C

6 Conclusion

The present work is a first step in the definition of safer and more reliable procedures to apply epoxy repair systems in through-the thickness flaws caused by corrosion in metallic pipelines. In these systems, the resin is applied directly over the flaw, with different procedures (eventually the piping segment is reinforced by wrapping it with concentric coils of composite material).

The main goal is to develop a systematic methodology, as simple as possible, to apply the resin in order to assure: (a) the safety of repairs under operation conditions and/or (b) the lifetime extension under operation conditions.

Conventional methods of repair include one of two ways: (a) cutting out the damaged segment of pipe and replacing it by welding in a new piece of pipe or (b) covering the pipe with a metal welded sleeve over the damaged area. The main advantages of this alternative repair technique are the economy of time to perform the repair and also the elimination of the necessity of heat treatment (in the welding operation there is always a possibility of metallurgical changes in the parent metal in

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the vicinity of the weld).

The experimental result show that the performance of the epoxy repair strongly depend on the resin and the way it is applied, but some of the system tested allowed very reliable and effective repairs, resisting pressure cycles of 1 hour with water at 30 kg/cm^2 and 80^{o}C. More adequate procedures to apply the resin can assure stronger repairs. For instance, an hydrostatic test performed with water at 80^{o}C in a 12" SCH 20 steel pipe with a repair of a hole of 10mm (system A) was interrupted when pressure reached 60 kg/cm^2 due to severe plastic deformation of the caps (figures 10 and 11) . A systematic procedure with additional tools (composite sleeves, etc. [3–7] is in development at the LMTA-UFF (Laboratório de Mecânica Teórica e Aplicada - Universidade Federal Fluminense).

Figure 10: 12" SCH 20 steel pipe with a repair of a hole of 10mm before and after testing

Figure 11: Deformed caps after testing at 60 kg/cm^2 and 80^{o}C.

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