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DEVELOPMENT OF TESTING FACILITY TO INVESTIGATE GRE PIPES BEHAVIOR IN HARSH ENVIRONMENT

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ABSTRACT

Oil and gas transmission pipes are made from metal or plastic tubes with inner diameters range from 4 to 48 inches (100 to 1,200 mm). Although carbon steel pipelines have been traditionally used in Oman, advanced composites are also introduced on limited scales. In Oman, the analysis of oil and gas pipelines failure that has been performed since 2007 has shown a relatively high incident of failure rate with carbon steel pipelines. A large percentage of the incidents involved were classified as pipe corrosion failure due to the harsh and corrosive environments (including high percentage of Hydrogen sulfide, H_2S). In this work, an in-house testing facility under controlled conditions has been developed in order to perform design verifications for the GRE pipes that will be used in oil and gas transmission lines in Oman according to the ASTM and ISO Standards. Two pipes are placed in an oven at a temperature of 65^{o}C and internal pressure of 130 Bars. One pipe contains water and the other crude oil with different H_2S concentrations (100 ppm, 300 ppm and 1000 ppm). The pipe has been left for a period of 1000 hours and will be taken for mechanical and material testing to assure performance and the relevant pipes design specifications.

1. INTRODUCTION

In comparing composites to steel pipes, there are a number of areas where composites are superior. It must be noted that currently, cost of composite pipe is higher on all fronts. Composites are produced, however, on life cycle cost assessment and maintenance advantages. Comparing relative flexural strengths, composites are significantly more flexible and lighter than steel. In fact, when strength-to-weight ratios are examined, composites can be much "stronger" than steel [1]. Other properties include easy installation, high durability and low maintenance and life cycle costs make them more desirable than conventional pipes. Composite are highly resistant to many corrosive chemicals and compounds, including H_2S.

A wide variety of applications has arisen that demand the use of chemical-resistant resins. By selecting from a range of resin chemistries, the specifying one can achieve the most cost-effective composites [2, 3]. Due to their attractive physical and mechanical properties GRE pipes have been successfully used in oil and gas this industry. A chemical composition analysis and properties of composite materials was outlined in [4]. The experimental work in this study has proposed that composite material is a sustrainable choice in oilfield applications. These are all highly dependent on the types of resin used, volume fraction of the reinforcement and its orientations [5].

The current procedure of qualifying GRE pipes in oil and gas applications is based on linear extrapolation method. It provides very good predictions of the long term behaviour of the pipes. This can be done by extrapolating the lower confidence limit from the regression line to rate for a design life time of 20 years [6].The in-house experimental setup proposed in this research study adopts a 1000 hrs. Short-term Survival Test based on ASTM D-2992 [7]. The test would predict the long term bahaviour of these pipes under such complex loading and, in particular, adverse environmental conditions. Particularly under multiaxial loadings involve combinations of hoop and axial loads as a result of high internal pressure and harsh chemicals (Hydrogen Sulphide, H_2S and Carbon Dioxide, CO_2). Sulphur mixed with water deep underground in the presence of heat and over thousands of years produces Hydrogen Sulphide (H_2S). It is a highly corrosive, and of course, deadly poisonous gas. Oil with H_2S content more than 500 ppm (part/million) in the gaseous state at atmospheric pressure is classified as ‘sour’. In Oman, sour oil and gas is mostly concentrated in the southern oil fields. Also, chemicals such as CO_2 are continuously injected into the oil reservoir in enhance oil recovery process for about 20 years. Therefore, it is necessary to investigate the chemical compatibility of these non-metallic materials in different environments. That is whether GRE pipes will survive the exposure to the given chemicals or not. One can collect extensive data from current experimental work, collate it, interpret it, and, eventually, manipulate it into a form with design curves.

Failure in oil and gas transmission lines during service is extremely serious. A large percentage of failure incidents in steel pipelines have been classified as pipe mechanical construction damage, corrosion failure and mechanical valve/fitting failures. Most of these steel pipelines have reached their limit life cycle of 20 years and the replacement of these pipes become very essential. The present work would offer GRE pipe as an alternative to the carbon steel pipes. Depending on their particular structural make-up, other important properties of composite materials include high corrosion and wear resistance, low thermal conductivity and thermal expansion. These distinctive characteristics provide design opportunities not possible with conventional monolithic metals. Consequently, unprecedented mechanical and physical properties can be tailored to meet the requirements of a particular application. However, difficulties are present when it comes to using composite pipelines. Such difficulties are primarily related to the lack of test data to support the materials' long-term behaviour and durability. The performance of the non-metallic materials (GRE) will be evaluated by investigating the mechanical properties, micro and macro cracks formation on the specimens after they are immerse in a mixture with the right concentration at a temperature of ~65^0C and a pressure of 130 Bar for a period of 1000 hours. A dedicated in-house test rig for GRE pipes has been developed with enhanced capacity of handling corrosive environment, i.e., the presence of H_2S and CO_2.

2. GLASS REINFORCED EPOXY PIPES

Helical Filament winding technique is used to manufacture GRE pipes. It is an automated open molding process. A continuous strand roving is pulled from a series of creels and passed through a resin bath before being wound onto a rotating mandrel in a variety of orientations, controlled by the fiber feeding mechanism and the winding speed of the mandrel to create the desired winding angle pattern and layup thickness [8].

Three GRE pipes were designed and manufactured with the following dimensions: 250-mm diameter, and 2.5-meter length. A thickness of 12-mm was identified to satisfy proposed design requirements, i.e., pressure class, temperature, leakage free and sustain the operating level of different of H_2S concentrations. ISO 14692 Standard has been adopted. The Standard describes how to qualify and manufacture GRE pipe and fittings [9]. A conventional automated helical winding machine is shown in Figure 1.

Figure 1: Helical filamnet winding used in Composite Pipes Industries (CPI) Oman

The orintation in helical filament winding comes with winding angle of ±55° as shown in Figure 2. This is the best orientation since the maximum allowable stress is aligned along the direction of the reinforements. Helical filament winding is process that produces high reinforcement content and thus leads to GRE pipes with excellent mechanical properties. After the desired architecture of the reinforcement has been achieved, the part is cured and removed from the mandrel.

Figure 2: A GRE pipe used in this study with a winding angle of ±55°.

The advantages of helical filament winding are, on one hand, the capability to automate the process and, on the other hand, the fact that the structural properties of the final product can be significantly tailored since the filament can be laid down in a complex pattern to match the strength-performance requirements [10]. In addition, this fabrication process can be used with both thermosetting and thermoplastic resins to provide excellent dimensional control and a high degree of uniformity and repeatability of the filament. The wall structures for the GRE pipes used in this worok are shown in Figure 3. Generally; the higher the pressure class, the greater the wall thickness of the pipe will be [11]. The wall structural used to manufacturing the three GRE pipes is given in Figure 3. It is considered during design and fabrication of the pipes to guarantee optimum working conditions under internal pressurized loading, high temperature and resistance of aggressive mixture of chemicals. The structural bulidup of the pipes wall is given in Table 1.

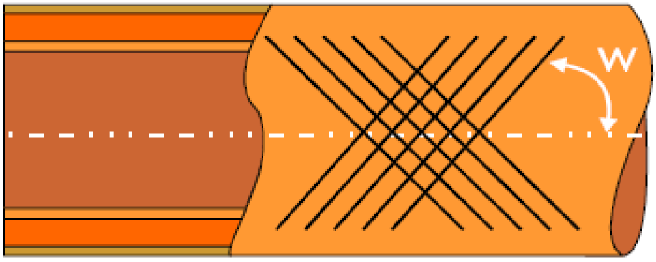

Figure 3: GRE pipe wall structures

	Resin	Glass	
0.3 mm Exterior Layer	100%	0%	Epoxy
Structural Wall	~ 25%	~ 75%	Epoxy + E-glass
0.5 mm Internal Layer	~ 90%	~ 10%	Epoxy + C-glass

Table 1: Structural Wall Build-up

The wall structural thickness of the pipe contributes to the overall stiffness of pipes. In this experimental work, the pipes were subjected to internal pressure of 130 Bars, temperature effect of 65°C and adverse and corrosive H_2S. However, during installation the pipes are buried and subjected to transverse loadings. Hence, the wall is built up to resist such type of loadings. A ring deflection (Split-desk) test of a specimen of the GRE pipes is considered to determine stiffness and resistance to structural damage to ensure that the pipes meet specified design constraints. This test will be illustrated and discussed in subsequent sections.

3. END-FITTING DESIGN

To conduct proper testing, which involves static pressurization of the GRE pipe, it is imperative to design an end-fitting suitable for the task. With such a “closed-end” test setup, the internal pressure caused by the pump is transferred to the pipe. Hence, a strong joint between the pipe end and the fittings is essential. End-fittings have been designed and customized for the test setup. The design of mechanical end-fitting flanges is shown in Figures 4 and 5 respectively The end-fitting contains loose-flange that can be split into two halves and blind flanges. Threaded holes on the blind flanges are used to attach pressure and temperutre gauges and valves. Carbon steel flanges are reliable for such type of closed-end test rig.

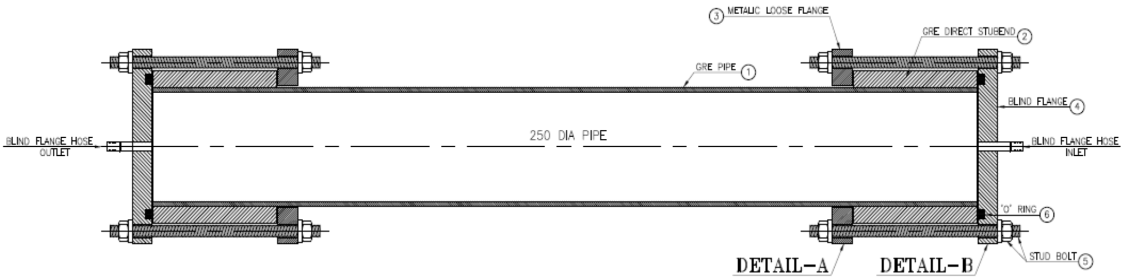

Figure 4: 2D drawing of the GRE pipes with end-fitting

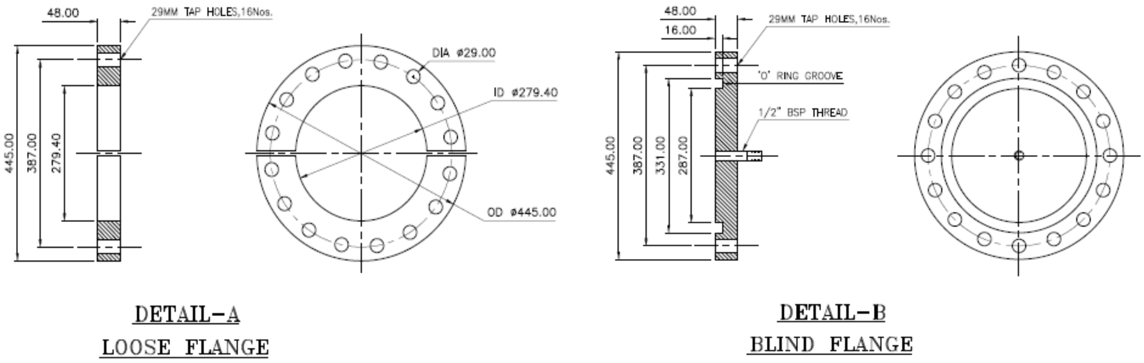

Figure 5: Detailed 2D drawings of the loose and blind flanges

4. THERMAL ENCLOSURE UNIT

Since elevated temperature performance is of a major interest in this study, a special custom-made thermal enclosure was designed and fabricated. It was specifically designed to enable the testing of pipe at temperatures up to 90°C and maintaining the test temperatures with a maximum variation of 3°C for 1000 hrs. The thermal enclosure unit is shown in Figure 6.

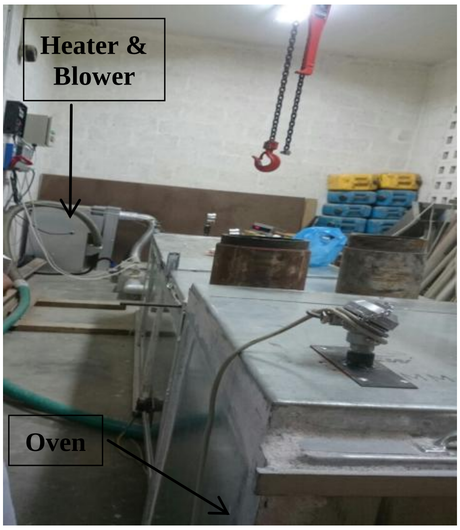

Figure 6: Thermal enclosure

The unit was designed so that the heater and the blower were separated from the oven space and placed at the back of the oven to achieve much better and more uniform control of test temperature, as well as to avoid any possible damage to the side of the wall during testing which would halt the operation of the oven. The closure was constructed with three holes to provide access for pressure tubing, temperature gage and instrumentation wiring. A photograph of the heater and the blower is given Figure 7.

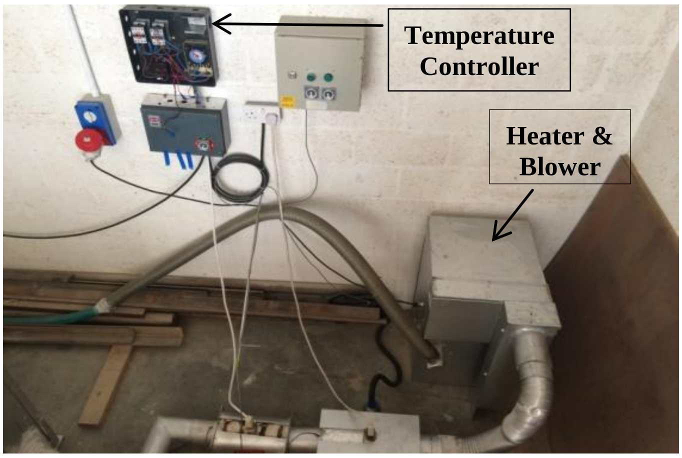

Figure 7: Heater and blower with temperature controller and switches

5. PRESSURIZATION SYSTEM

The pressure system was designed so that it could facilitate a maximum working pressure up to 130 Bars. The second GRE pipe ready to be placed into the thermal enclosure is shown in Figure 8. The end-fittings were fixed at each end of the test specimen with bolted joints for tests at 65°C. GRE pipes used for high pressure and high temperature are wound with reinforcemnts angled helically at ±θ° to the axial load of the mandrel. The strength and stiffness of a composite buildup depends on the orientation sequence of the reinforcements. In this experimental study the pipes were produced at ±55° angles.

Figure 8: GRE pipe with end-flanges

The pipe was then pressurized to create pressure class that tends to generate a state of complex hoop-to-axial loading conditions. This was achieved by using a differential pump driven by an air compressor via a ball valve, see Figure 9. The pump flow rate is managed by using a pressure regulator installed in the compressed air inlet to the pump. The pressure loading was controlled manually by the opening and closing of the unloading valve. During pressurizing, the valve was kept closed. Once the pressure required was reached and held for the required amount of time (1000 hrs.), the pressure was released by opening the unloading valve. It was noted that a drop in pressure in the pipe occurred almost immediately when the valve was opened. The short-term survival test procedure is based on ASTM D-2992 and ASME 1598 [12].

Figure 9: Differential pump

6. RESULTS AND DISCUSSION

Three GRE pipes have been designed and fabricated at Composite Pipes Industry of Oman. The first pipe is shown in Figure 2. This pipe has been used as a reference pipe to collect some useful benchmarking information on the pipes mechanical properties such as maximum applied force, maximum stresses in longitudinal and circumferential direction. Preliminary set of tensile testing and split disk testing have been performed on specimens taking from this pipe, as shown in Figures 10 (a), (b) and Figures 11 (a), (b). In Figure 11, tubular specimens for split disk test were cut from the 2.5 m length pipe. The mechanical testing was carried out on a 150 kN Dartec hydraulic test frame.

Figure 10: Benchmark pipe speciemns prepared for tensile testing of with (a) Axial, (b) Transverse starin gages

Results produced from tensile test and split-disk test appear to provide an efficient means to assess performance of second and third pipes in such harsh environment. The second GRE pipe has been subjected to high pressure 130 Bars and high temperature 65^0C conditions since April 20, 2015. The proposed test is taking 1000 hrs. The effect of elevated temperature and high pressure on the integrity and the long term durability of the pipes has been undertaken. The procedure for determining the strength of the GRE pipes under such conditions is based on ASTM Standard D-2992. Whereas, the influence of harsh chemicals such as H_2S and CO_2 on the reinforcements will be investigated thoroughly using the third GRE pipe. The controlled chemical condition is very close to realistic situations. The third pipe contains crude oil with different concentrations of H_2S (100 ppm, 300 ppm and 1000 ppm).

(a)

(b)

Figure 11: Specimen for Split-disk test (a) with starin gages attached axially and circumferentially, (b) Split-disk speciemn with fixtures

Failed tensile test and split-disk speciemns illustrated in Figures 12 and 13 indicate failure mechanism which is often characterized by complex combinations of reinforcement and resin failures.

Figure 12: Failed tensile test specimen

The tensile test specimen and the split-disk specimen were loaded beyond the onset of the original failure. This prompted large deformation and damage into the original failure. Observations taken during testing as well as the characteristics of the failed specimens have shown that cracks started along the ring axis; in particular, in split-disk specimen followed by a rupture in the GRE ring wall where the reinforcements started to tear and creates an opening in the structural wall of the specimen as shown in Figure 13. A subsequent experimental work is undertaken to understand the onset of failure and the failure mechanism as a result of the interaction of high pressure, high temperature in the presence of chemicals compounds.

Figure 13: Failed split-disk specimen

7. CONCLUSIONS

This work concerned with developing an in-house testing facility that is capable to simulate the conditions required to perform design verification for GRE pipes according to ASTM and ISO standards. In addition, this facility has the capability to investigate the effects of other harsh conditions, mainly, the effects of H_2S and CO_2 on the GRE pipes. Two similar pipes are placed in a thermal enclosure unit at a temperature of 65^oC and internal pressure of 130 Bars. One pipe contains water and the other crude oil with different H_2S concentrations (100 ppm, 300 ppm and 1000 ppm). The pipe has been left for a period of 1000 hours and will be taken for mechanical and material testing to assure performance and the relevant pipes design specifications. A third similar pipe was selected to be a reference to collect some useful benchmarking information on the pipes mechanical properties such as maximum applied force, maximum stresses in longitudinal and circumferential direction. Preliminary set of tensile testing and split disk testing have been performed on specimens taking from the reference pipe and results will be used to compare its mechanical responses with the other two pipes subjected to the 1000 hours test.

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REFERENCES

[1] I.M. Daniel, O. Ishai, *Engineering Mechanics of Composite Materials*, Oxford University Press, Oxford, 2006.

[2] A.G. Gibson, Composite materials in the offshore industry. *Metals and Materials*, **5(10)**, 590–594, 1989.

[3] A.G. Gibson, The cost effective use of fiber reinforced composites offshore. Report submitted to the Health and Safety Executive, Centre for Composite Materials Engineering, University of Newcastle Upon Tyne, UK, 1–140, 2003.

[4] M.E. Hossain, The current and future trends of composite materials: an experimental study. *Journal of Composite Materials*, **45(20)**, 2133–2144, 2011.

[5] S. Mazumdar, *Composites Manufacturing: Materials, Product, and Process Engineering*, CRC Press, Taylor and Francis Group, 2002.

[6] Future Pipes Industires, *Engineering Guide for Wavistrong Filament Wound Epoxy Pipes*, 2001.

[7] ASTM D-2992, Standard practice for obtaining hydrostatic or pressure design basis for fiberglass (glass-fiber-reinforced thermosetting resin) pipe and fittings, American Society of Testing and Materials, 1996.

[8] P.K. Mallick, *Fiber-Reinforced Composites: Materials, Manufacturing and Design*, CRC Press, Taylor and Francis Group, 2007.

[9] ISO 14692 Standard, Parts 1-4, International Standards Organization, 2002.

[10] F.C. Shen, A filament-wound structure technology overview, *Materials Chemistry and Physics*, **42 (2)**, 96–100, 1995.

[11] P.D. Soden, R. Kitching, P.C. Tse, Experimental failure stresses for ±55 filament wound glass fibre reinforced plastic tubes under biaxial loads. *Composites*, **20(2)**, 125–35, 1989.

[12] ASTM D-1598, Standard Test Method for Time-to-Failure of Plastic Pipe Under Constant Internal Pressure, American Society of Testing and Materials, 2009.