CLOCK SPRING®

Leak Stop Repair System

The Fast, Economical Solution for Pipeline Repair

For many years Clock Spring Company LP has been at the forefront of pipeline repair using composite technology, being well known with pipeline operators in over 60 countries. With over 100,000 units used to date the 100% success rate speaks for itself.

Over the years Clock Spring has endeavoured to develop their product range in order to provide the pipeline operator with an ideal repair solution for a range of problems. New products have included Snap Wrap (a split sleeve system for low pressure applications) and Pipe Support (a unique and permanent solution to corrosion problems associated in support areas).

Clock Spring have continued to develop the Leak Stop product specifically aimed at leaking and through-wall defects. A large amount of in-house testing has been conducted over the years and proven the product to be a viable and successful repair solution. Clock Spring decided to involve a third-party company that would conduct extensive test procedures and qualify the product against other composite repairs available on the market.

The following pages are the final report from a series of tests that were carried out by the AEA (Atomic Energy Authority). Members of this particular workgroup include many major pipeline operators from around the world and the purpose was to test the performance of a variety of composite repairs on leaking defects. 2 tests were performed to qualify the product and are detailed in the following pages.

Although not permitted to disclose results of all composite repairs (4 in total) tested, we can confirm that the results obtained by Clock Spring were well beyond expectation. In summary:

- The estimated average short-term failure pressure on a 25mm diameter defect is 125 Bar.
- The predicted failure pressure of an 'unplugged' (worst case scenario) 25mm defect after 20 years is 78.45 Bar.

- The estimated degradation factor of the Clock Spring repair over a period of 20 years is 1.58 and lower than that of GRP pipe and other composites – the estimated time of failure for a 25mm defect at a pressure of 61 Bar is $1.36*10^8$ hours.

Following information is taken from AEA document AEAT/57394 – Composite Overwrap Repairs – Medium Term Testing & Analysis.

Medium test procedures

CHOICE OF TEST PROCEDURES

The aim of the medium term test programme is to verify current design approach for the repair of leaking defects. The challenge in the development of a medium term test procedure is to select a method of loading the samples so that the test duration i.e. time to repair failure, is approximately 1000 hours (6 weeks). The choice of 1000 hours as a test time is based on experience with GRP pipes. This length of time is long enough to remove the influence of short term effects yet long enough to ensure that long term failure processes are represented at failure.

The testing programme considered two types of tests, a low speed loading rate test and a constant pressure test.

The low speed loading rate test, as its name suggests, involves the load being increased gradually (usually linearly with time) from an initial load until repair failure. The constant pressure test, is simply, application of a constant pressure until failure.

In order to select the appropriate test pressure and loading rate, an assumption is made regarding the degradation of repair laminate, namely that it is proportional to the degradation of plain GRP pipe, i.e. their regression behaviour or gradient (degradation as a function of time) is similar.

For GRP pipes the ratio of mean 1000 hour failure pressure to average short term burst pressure is approximately 75%. To equate short term pressures to long term pressures it is assumed that the duration of a short term burst test is 1 hour.

However, the selection of a test pressure without accurate knowledge of the long term performance of the repair, i.e. precise quantification of the degradation factor, may lead either to the repair failing quicker than expected, or surviving much longer than expected. Figure 1 presents a normalised regression curve for plain GRP pipe. The vertical axis is Log(normalised pressure with respect to short term burst pressure) against (horizontal axis) Log(time) in hours. Included in this figure are the upper and lower 95% confidence limits of the regression curve. If the applied pressure for the medium term (1000 hours) is accurately defined then from Figure 1 the expected time to failure of the repair will fall approximately within the 95% confidence limits, represented by the time period 533 to 1876 hours (brown line).

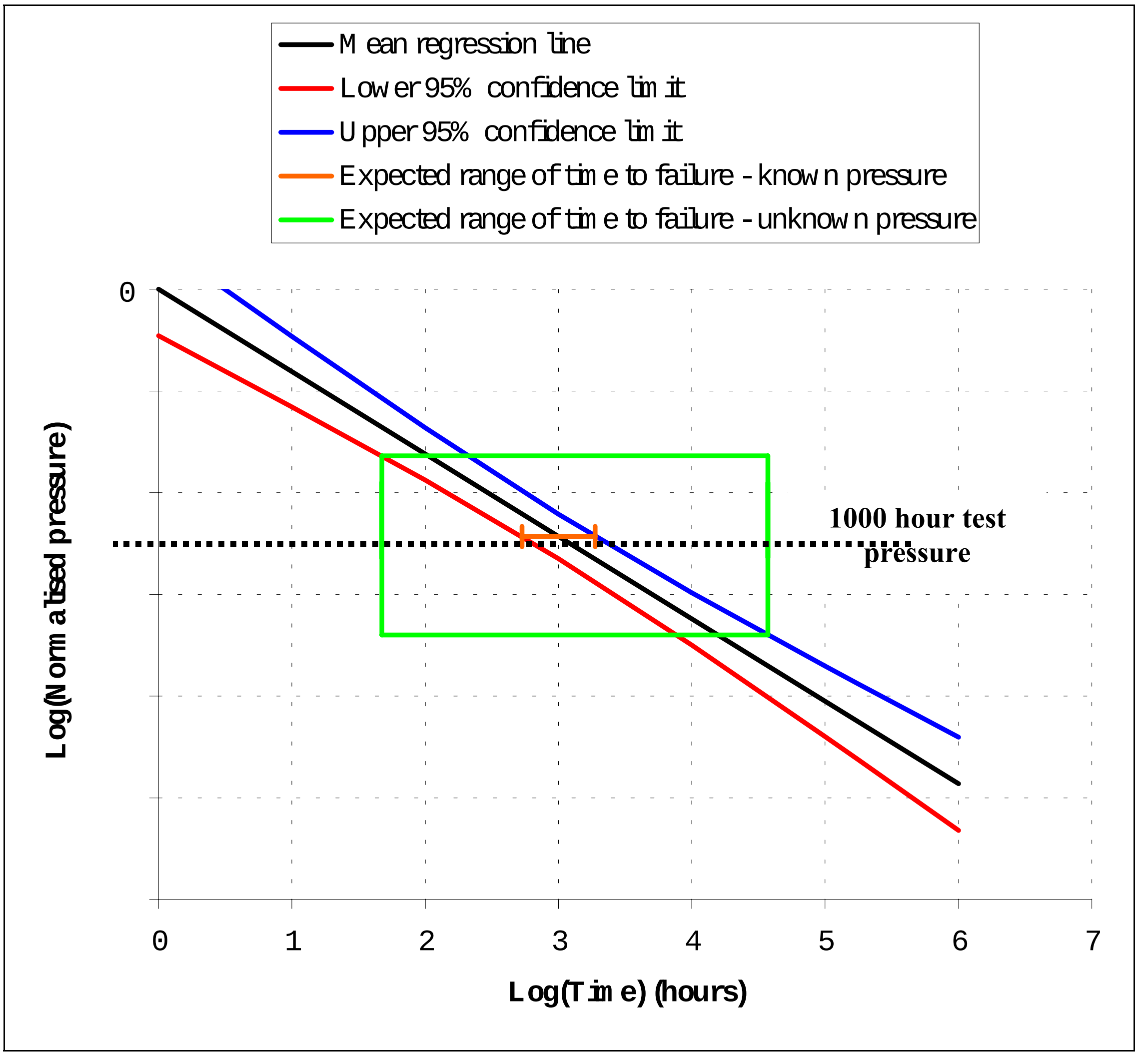

Figure 1: Normalised regression behaviour of GRE pipes – constant pressure loading

However, current short term burst pressure results of commercially available composite overwrap repairs suggest that the range in short term burst pressures is approximately ±25% from expected values. If this variation in failure pressures is extended to the mean 1000 hour test pressure then the time period for expected failures increases to 48 to 37,210 hours (see Figure 1, green rectangle). This potential range in test times to failure for a constant pressure test is too great to be of practical use.

Therefore, to fix the medium term failure pressure of a composite overwrap repair, without precise knowledge or data on its long term performance, a constant pressure test is from an experimental perspective, not ideal. However, a low speed loading rate (LSL) test has the potential to determine the medium term test pressure without adding large uncertainties to the time to failure of the repairs.

Figure 2 presents stress against time curves for two LSL tests. LSL tests are chosen to estimate both the medium term failure pressure and also regression behaviour because the variability in the time to failure of the LSL test is much smaller than for the constant pressure test. The analogy that can be used to explain why the variability is less is that of intersecting lines. Two lines almost parallel have a large potential intersection zone (constant pressure test and regression curve) whereas lines that are close to being perpendicular (LSL test and regression curve) have a well defined intersection point. The disadvantages of the LSL test are that a degree of uncertainty is introduced into the failure pressure and a more complicated pressure delivery system is required. By performing two LSL tests at different loading rates (and initial pressures, although not necessary) the regression curve can be generated from the two failure points as shown in Figure 2. Note, the second LSL can be a short term burst test.

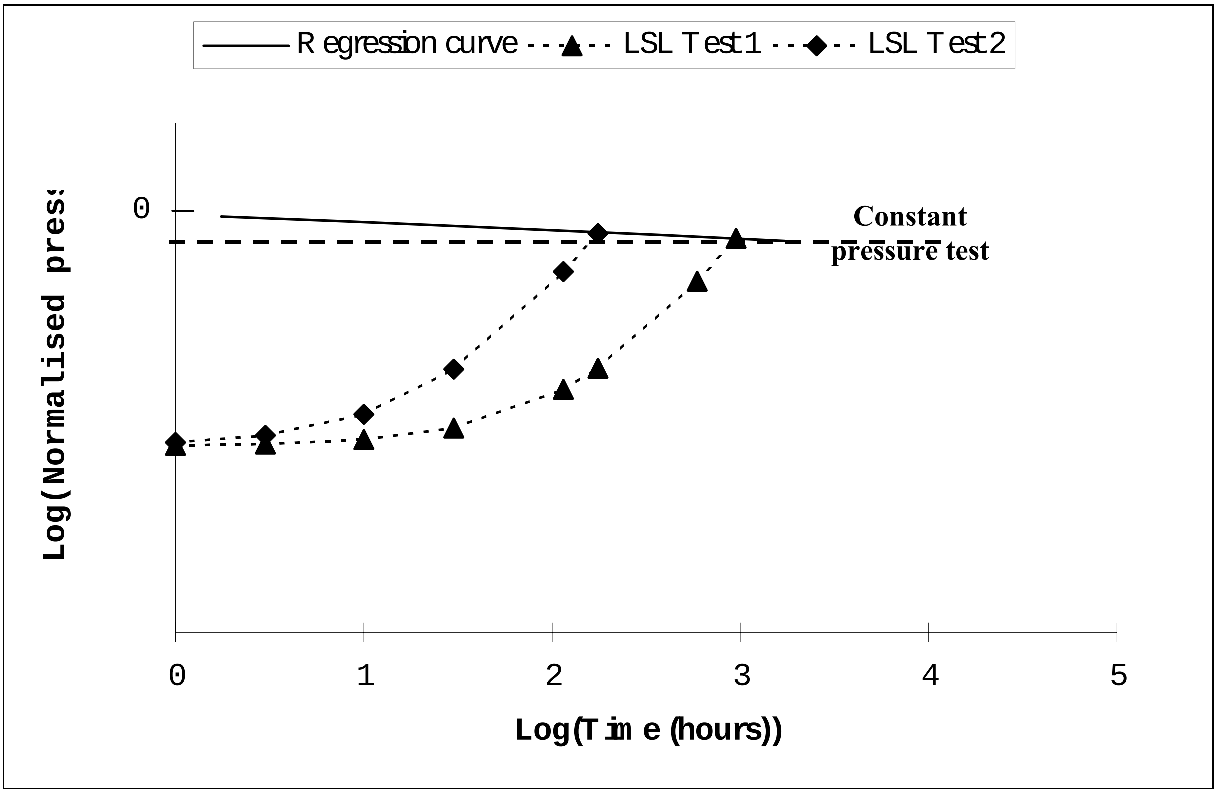

Figure 2: Low speed loading (LSL) tests with curves explaining test principal.

To infer a regression curve from two LSL tests, Miners Law is invoked;

$$\int_0^{t_f} \frac{dt}{t(p)} = 1 \tag{1}$$

where t_f is the time to failure and $p(t)$ is the applied pressure as a function of time.

The regression curve is defined as;

$$\log(p) = A - B\log(t) \qquad or \qquad t = \left(\frac{p}{A^*}\right)^{-1/B} \tag{2}$$

where $A=log(A^*)$ and B are the unknown constants. Note, B is termed the regression gradient.

Inserting Equation (2) into Equation (1) gives;

$$\int_0^{t_f} \left(\frac{p}{A^*}\right)^{1/B} dt = 1 \tag{3}$$

Considering a linear LSL test, i.e.

$$p(t) = p_0 + \dot{p}t \tag{4}$$

where p_0 is the initial pressure (bar) and $\dot{p}$ is the fixed linear increase in pressure (bar/hour). Inserting Equation (4) into Equation (3) gives;

$$\frac{1}{\left(A^*\right)^{1/B}}\int_0^{t_f}\left(p_0+\dot{p}t\right)^{1/B}dt=1 \tag{5}$$

Integrating gives the time, t_f, to and pressure at failure, p_f, of the LSL test as a function of the regression curve constants, A and B, i.e.;

$$p_f=\left[\left(A^*\right)^{1/B}\dot{p}\left(\frac{B+1}{B}\right)+p_0{}^{\frac{B+1}{B}}\right]^{\frac{B}{B+1}} \quad \text{and} \quad t_f=\frac{p_f-p_0}{\dot{p}} \tag{6}$$

For two LSL tests resulting in times to and stresses at failure of, $t_{f,1}$, $t_{f,2}$ and $p_{f,1}$, $p_{f,2}$ respectively then the regression coefficients A and **B** can be derived as follows, assuming $p_f >> p_0$;

$$A=\log\left(\frac{p_{f,1}}{t_{f,1}^{-B}}\right) \quad \text{and} \quad B=\frac{1}{\left(\frac{\log\left(\frac{\dot{p}_1}{\dot{p}_2}\right)}{\log\left(\frac{p_{f,1}}{p_{f,2}}\right)}\right)-1} \tag{7}$$

From Equation (7), the constant applied pressure required for failure after 1000 hours is given by;

$$p_{1000\,\text{hour}}=10^{(A-3B)} \tag{8}$$

The above discussion has indicated that the sequence of medium term testing should be first a low speed loading rate test, to fix the medium term failure time and pressure, followed by a constant pressure test. By performing both tests on the (nominally) same composite overwrap repair will provide the information and corroboration needed to define the degradation factor between the short and long term performance.

The aim of the medium term tests is to estimate the degradation of the repair over its lifetime. Assuming that the short term burst pressure test can also be described as an LSL test with a test duration of 1 hour, then from the regression constants, Equation (7), this ratio of short term burst pressure to 20 year failure pressure, defined as the degradation factor, is given by;

$$\text{Degradation factor}=\frac{1}{10^{-5.24B}} \tag{9}$$

(Note: 5.24 is the logarithm of 20 years expressed in hours). In Equation (9) the degradation factor is solely a function of the regression gradient, B.

SPOOL-PIECE DIMENSIONS

The test samples or spool piece dimensions for the medium term tests are as follows:

- 6 inch diameter pipe, Schedule 40, length 0.75 meters
- Class 600 weld-neck flanges welded to both ends to the pipe.
- Class 600 blind flanges (with pressure tapings) bolted to the weld-neck flanges.

For ambient conditions, the pressure rating of Class 600 fittings is 100 bar.

The defect is centred in the test sample (pipe) and is circular with a diameter of 25 mm. The defect is actually a 5 mm hole within the pipe, with a PTFE ring of external diameter 25 mm.

Repairs from 4 suppliers were tested. Each supplier was asked to provide 3 identical repairs such that for a 25 mm diameter defect the short term burst pressure of the repair would be 100 bar. In total, 12 spool-pieces were tested. Figure 3 shows a photograph of the test arrangement.

Figure 3: Test spool arrangement

REPAIR APPLICATION AND PRESSURE TEST DETAILS

The repair application and pressure test sequence was;

- Apply repair, perform LSL test
- Remove repair, re-apply repair, perform constant pressure test

Repairs were removed by Ultra High Pressure Water jetting. All tests were performed at ambient conditions with water as the pressurising medium. Measured output from each test was pressure as a function of time until failure.

Low speed loading rate test – An initial estimate of the medium term failure pressure is 75 bar based on plain GRP pipe performance. Therefore, the initial pressure, p_0, was set at 21 bar and the pressure raised linearly at 3 bar/day during weekdays, i.e. 15 bar pressure increase over a 7 day period, implying a loading rate, $\dot{p}$, of 0.09 bar/hour until failure. Based on these LSL parameters, the estimated time to failure is 600 hours. Pressure and test duration were recorded daily.

Constant pressure tests - The pressure of these tests was based on the measured failure times from LSL tests. The output of these tests was for the given test pressure (fixed), failure time for each repair. Pressure and test duration were recorded daily.

Test results - low speed loading rate tests

The results for the low speed loading rate tests for each supplier and subsequent analysis is described in the following sections.

Within these sections LSL_1 refers to the low speed loading rate test, as described in Section 4.3, i.e.

$$p_1 = p_{0,1} + \dot{p}(t)_1 * t = 21 + 0.09 * t$$

The initial pressure of the tests was 21 bar with the pressure increasing linearly at 0.09 bars/hour.

LSL_2 refers to the short term burst test on the same geometry and defect. Where actual short term test data (i.e. short term burst tests on 6 inch pipe with a 25 mm diameter defect) is not available an estimate of the short term burst pressure is made from other short term results. The short term burst test or LSL_2 is defined as;

$$p_2 = p_{0,2} + \dot{p}(t)_2 * t = 0 + \dot{p}(t)_2 * 1 = \dot{p}(t)_2$$

To equate the short term burst test in terms of LSL test parameters it is assumed that the duration of a short term burst test is 1 hour. The measured failure pressure of the short term burst test is therefore equated to the hourly rate of pressure increase.

From LSL_1 and LSL_2 a prediction of the regression curve constants, A and B, defined in Equation (2) can be made using Equation (7). From the regression gradient, B, the degradation factor can be calculated, Equation (9).

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The times to failure of the 3 tests for the Clockspring repairs were as follows;

Test number	Time to failure (hours)
1	No failure
2	No failure
3	840

It should be noted that for the 2 tests that did not fail, both had plugs or bungs fitted into the hole or defect. The failure mode from the single failed repair (which had no bung in the defect) was leakage from the interface at the edge of the repair. Tests on the remaining samples were stopped at 100 bar, as this was the maximum design pressure of the test spools.

Based on inference of other data and analysis, the short term burst pressure of the repairs was estimated as 125 bar for the given defect. Therefore, a summary of the LSL tests and analysis of the test data to deduce the regression constants, A and B is as follows;

	LSL_1	LSL_2

Time to failure (hour)	840	1
Pressure at failure (bar)	96	125
P_0 (bar)	21	0
$\dot{p}(t)$ (bar/hour)	0.09	125
A	2.093	
B	0.038	
Predicted 20 year failure pressure (bar)	78.45	
Degradation factor	1.58	

Only the single failure LSL test is used in the analysis of the data. The estimated degradation factor is 1.58. This value is lower than the assumed value of 2 in the design document, AEAT-57711.

Test results – constant pressure tests

Based on the low speed loading rate tests (Section 5) the choice of pressure for the constant pressure tests was set to 61 bar. This choice of pressure was based on the average performance of all repairs tested. It was anticipated that some repairs would fail before 1000 hours while other would last longer. The choice of 61 bar was selected as a compromise between repairs lasting significantly longer than 1000 hours and others failing at or shortly after the application of pressure.

The actual pressure loading sequence involved raising the pressure initially to 72 bar then isolating the individual test spools. Over a 120 hour period, the pressure within each of the spools settled down to the intended operating pressure of 61 bar. This variation in pressure was primarily due to the daily temperature fluctuations and the pressurising medium, water, stabilising to the ambient temperature of the test.

The test results for the constant pressure tests is as follows;

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The time the Clockspring repairs were subjected to an average constant pressure of 61 bar was as follows;

Test number	Time (hours)
1	No failure after 1632 hours
2	No failure after 1632 hours
3	No failure after 1632 hours

After 1632 hours, all test samples were subjected to an increasing daily pressure of 2.16 bar/day (0.09 bar/hour). Theses tests were stopped when the pressure reached 100 bar, after a further 448 hours. No failure of any of the test samples was recorded.

Specific conclusions

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The long term failure mode for leaking defects is delamination of the interface between the steel substrate and the composite laminate. The following conclusions are based on the tests with no bung placed within the defect.

The estimated average short term failure pressure of the repairs for the given defect size of 25 mm diameter was 125 bar for a repair thickness of 15.75 mm.

The average time to failure of the low speed loading rate tests was 840 hours corresponding to an average failure pressure of 96 bar.

For the constant pressure tests, all 3 samples survived 1632 hours at 61 bar.

Analysing the low speed loading rate test results using Equation (7) implies the predicted regression gradient, B is 0.038, and the 20 year degradation factor is 1.58, less than the assumed value of 2 in the design document, AEAT-57711 [1]. Using this value of regression gradient, the estimated time to failure of the constant pressure test is $1.36 \ast 10^8$ hours.