A TEST METHOD TO DETERMINE
THE SUSCEPTIBILITY TO
CRACKING OF LINEPIPE STEELS
IN SOUR SERVICE

Prepared by Capcis Ltd for the
Health and Safety Executive
HYDROGEN SULPHIDE (H₂S) - HEALTH AND SAFETY CONSIDERATIONS

Chemical and Physical Properties

Colourless gas with strong characteristic odour of rotten eggs.

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Molecular weight</td>
<td>34.08</td>
</tr>
<tr>
<td>Specific gravity</td>
<td>1.19 (air = 1)</td>
</tr>
<tr>
<td>Melting point</td>
<td>-82.9°C</td>
</tr>
<tr>
<td>Boiling point</td>
<td>-60.33°C</td>
</tr>
<tr>
<td>Flammable limits in air</td>
<td>4.3 - 45% (by volume)</td>
</tr>
<tr>
<td>Auto ignition temperature</td>
<td>260°C</td>
</tr>
<tr>
<td>Vapour pressure (20°C)</td>
<td>17.38 bar (g)</td>
</tr>
<tr>
<td>Solubility</td>
<td>437 ml in 100 ml water @ 0°C</td>
</tr>
<tr>
<td></td>
<td>180 ml in 100 ml water @ 40°C</td>
</tr>
<tr>
<td></td>
<td>Also soluble in alcohol, petroleum solvents and crude petroleum.</td>
</tr>
</tbody>
</table>

Weak Acid

\[ H_2S \leftrightarrow HS^- + H^+ \quad pKa = 6.88 \]

\[ HS^- \leftrightarrow S^{2-} + H^+ \quad pKa = 14.15 \]

Dry hydrogen sulphide is not particularly reactive to common metals. Much more reactive at higher temperatures, moist conditions and the presence of carbon dioxide also increase the reaction rate. Forms characteristic shallow pits. Can induce various forms of cracking in steels, see later section.

Physiological Effects

Hydrogen sulphide is an extremely toxic substance and working with it requires careful planning, monitoring and control. In the UK its use in the workplace is subject to the Control of Substances Hazardous to Health Regulations 1988 (COSHH). Approved occupational exposure limits for hydrogen sulphide have been set by the UK Health & Safety Commission. The current levels are 10 ppm for long term exposure based on an 8 hour working day and 15 ppm for short term (10 minute) exposure. Similar regulations apply in many other countries and advice should be sought from the regulatory body in the country concerned.

Additional information on the toxicity of hydrogen sulphide can be obtained by consulting the Material Safety Data Sheet provided by the manufacturer or distributor and from consulting sources such as Dangerous Properties of Industrial Materials by N Irving Sax, published by Reinhold Book Corp, New York, NY.

Fire and Explosion Hazards

Hydrogen sulphide is a flammable gas, yielding poisonous sulphur dioxide as a combustion product. Its flammable limits range from 4.0 to 46% in air. Its auto-ignition temperature is 260°C. Sulphur dioxide is the result of combustion in air. Appropriate precautions should be taken to prevent these hazards from developing.

A secondary containment chamber is recommended for conducting full ring tests. However, for large diameter sections, where a large volume of H₂S saturated liquors are used, a separate safety enclosure, sealed from leaks and monitored, is required.

1 'Occupational Exposure Limits for use with COSHH', EH 40, HSE Information Centre, Broad Lane, Sheffield, UK.
SUMMARY

Sour service problems in pipeline steels are caused by the various forms of hydrogen damage due to the presence of wet hydrogen sulphide. The main mechanisms are hydrogen pressure induced cracking (HPIC), sulphide stress corrosion cracking (SSCC) and stress oriented hydrogen induced cracking (SOHIC). Over the past 20 years a number of laboratory test methods to predict the behaviour of steels in sour service have been developed. One of the best ways of assessing pipeline steels is to stress a full ring specimen of the linepipe in a sour environment. This can be achieved by welding end caps onto the sample and pressurising it with a suitable gas or liquid medium.

The advantage of the full ring test described in this report is that it is not necessary to pressurise the linepipe full ring specimen in order to achieve the required stress loading. Equivalent stresses can be produced using mechanical means to deform the pipe by ovalisation. The validity of this approach has been demonstrated in theory and in practice.

This test uses well tried experimental procedures to exert a known stress level on a full section of pipe steel. The pipe specimen is then exposed internally to the test solution. Ultrasonic monitoring and hydrogen permeation measurements are conducted regularly during the exposure period. Both crack initiation and propagation can therefore be monitored. Finally, a metallographic study of indications is made to classify any defects found by the ultrasonic survey.

The method has been in use since 1984, but in 1991, a Joint Industry Sponsored Project was set up with the aim of systematically developing, defining and validating the full ring test. This procedure details a test method designed to determine the susceptibility of pipeline steels, bends, flanges and fittings including all associated welds to hydrogen damage caused by exposure to wet sour (H₂S containing) environments.
FOREWORD

Sulphide stress corrosion cracking (SSCC) and hydrogen induced cracking (HIC) have long been recognised as a potential problem when carbon and low alloy steels are exposed to wet sour environments. More recently, stress oriented hydrogen induced cracking (SOHIC) has also become an industry-wide problem.

The action of a sour environment has been responsible for a number of pipeline and vessel failures. The mechanisms of the different types of cracking which can manifest themselves vary, however, all involve hydrogen. There is a clear need for a laboratory based test method which can be used to evaluate the susceptibility of steels to all the various forms of cracking due to sour service. Full scale pressure testing of linepipe has major disadvantages with regard to safety requirements and size. Small scale tests using coupons, etc., have the disadvantages of sample selection, release of residual stresses, and multi-side surface exposure.

The full ring test overcomes these disadvantages and has been the subject of a Joint Industry Sponsored Project, the aim of which was to define, evaluate, validate and publish the test method in sufficient detail for any competent sour service laboratory to be able to undertake the test. Table 1 compares the Full Ring Test with the small scale tests commonly used.

SSCC requires the combined action of stress (residual and/or applied) and the corroding environment, namely, wet H₂S. The tensile stresses can cause failure at levels well below the yield stress of the material.

SSCC failures in some alloys are generally believed to result from hydrogen embrittlement but since the hydrogen is being cathodically evolved as a result of corrosion in an aggressive environment (hydrogen sulphide in an aqueous environment) while the material is under stress, the phenomenon is deemed to be SSCC. In some cases failure may be the result of localised anodic corrosion processes where hydrogen may or may not be involved. Such failures may, at times, fall into the category of SSCC even though their cause may not be hydrogen.

For sulphide stress corrosion cracking to occur a combination of tensile stress (applied and/or residual), corrosive environment and susceptible material is required. Stresses found within pipework systems are predominately tensile and by definition this report deals with wet sour oil and gas service which is a highly corrosive environment.

HIC requires only the corroding environment. The absorption of atomic hydrogen generated by the corrosion of steel in wet hydrogen sulphide (H₂S) can have several effects depending upon the composition and microstructure of the steel and the characteristics of the environment.

The hydrogen evolution reaction takes place in two stages:

Stage 1 \[ 2H^+ + 2e^- \rightarrow 2H_{ads} \] (adsorbed atomic hydrogen gas)

Stage 2 \[ H_{ads} + H_{ads} \rightarrow H_2 \] (evolved gas)

Each stage has its own activation energy and rate constant (K_1, K_2) with the slower stage being the 'rate-determining' step of the overall hydrogen evolution process. It follows that if Stage 2 becomes the controlling step, then atomic hydrogen can accumulate at the surface to the extent where it may induce diffusion into the metal crystals producing catastrophic results such as embrittlement or even in the case of high strength ferrous alloys, hydrogen cracking.
The presence of sulphides tends to increase the amount of atomic hydrogen available. This reaction is brought about by the presence of the HS\(^-\) ion which exists in equilibrium with the \(H_2S\).

\[
H_2S \rightarrow HS^- + H^+ 
\]

The lattice spacing for iron alloys is such that hydrogen atoms are able to diffuse through the lattice as an interstitial element.

The rate of diffusion is highly dependent upon temperature. Hydrogen atoms tend to recombine at dislocations and at non-metallic inclusions or voids within the steel lattice forming pockets of molecular hydrogen gas under pressure. If the stresses created in the surrounding steel cannot be relieved by movement of dislocations, fracture occurs.

There are many terms used to describe failures of this kind, e.g:

- Hydrogen induced cracking (HIC)
- Hydrogen pressure induced cracking (HPIC)
- Blister cracking (HIBC)
- Stepwise cracking

**SOHIC** is a combination of both SSCC and HIC and generally requires some element of stress, together with the sulphide containing environment. SOHIC starts by the initiation of hydrogen induced cracks referred to as 'latent initiants'. These are linked together by secondary SSCC across the wall thickness. The feature of SOHIC is that it develops in the through thickness direction across the wall.

Experience shows that SOHIC is most likely to occur close to a weld due to residual stress effects, although coupling effects due to minor differences in chemistry may also be a contributory factor.
### TABLE 1

**COMPARISON OF TEST TECHNIQUES**  
Standard TM0284, TM0177 and Full Ring Test

<table>
<thead>
<tr>
<th>Sample Selection</th>
<th>TMO284-87 HIC Test</th>
<th>TM0177-90 Smooth Tensile</th>
<th>4pt Bend/C-Ring</th>
<th>FULL RING TEST</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coupons may not be representative of a pipe section.</td>
<td>Restricted</td>
<td>Restricted</td>
<td>Full circumferential ring tested, including all welds, HAZ and plate</td>
</tr>
<tr>
<td>Test Duration</td>
<td>96 hours (was originally designed for pipe of ½&quot; thickness)</td>
<td>30 days</td>
<td>30 days</td>
<td>30 days allows for delayed crack initiation to occur (HIC)</td>
</tr>
<tr>
<td>On-line Monitoring</td>
<td>Not possible</td>
<td>Not possible</td>
<td>Not possible</td>
<td>Ultrasonic testing, on-line hydrogen permeation possible.</td>
</tr>
<tr>
<td>Surfaces Examined</td>
<td>Machined faces of coupons</td>
<td>No real surface examined.</td>
<td>Real and other surfaces tested</td>
<td>Inside surfaces Sa 2½/ST3* as often stipulated in Company Specifications</td>
</tr>
<tr>
<td>Residual Stress</td>
<td>Nil - removed when samples machined</td>
<td>Nil removed when samples machined</td>
<td>Nil-removed when samples machined</td>
<td>Full residual stress of manufacture and welding retained</td>
</tr>
<tr>
<td>Testing of Girth Weld</td>
<td>Not usually specified</td>
<td>Restricted</td>
<td>Possible but difficult - stress direction 90° to reality</td>
<td>Full weld included</td>
</tr>
<tr>
<td>Testing of Longitudinal Weld</td>
<td>Unstressed and machined condition only</td>
<td>Tensile specimens - no weld profile or HAZ</td>
<td>Included but often machined</td>
<td>Full weld tested</td>
</tr>
<tr>
<td>Total Stress Condition</td>
<td>Nil</td>
<td>Percentage of yield only</td>
<td>Percentage of yield only</td>
<td>Residual and applied stress</td>
</tr>
<tr>
<td>Coupling of Dissimilar Materials</td>
<td>Is possible, but not included in Specification.</td>
<td>Is possible.</td>
<td>Is possible</td>
<td>Full coupling and also residual stress retained</td>
</tr>
</tbody>
</table>
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THE FULL RING TEST

1. GENERAL

This test method utilises a full circumferential ring of linepipe. The test piece can also consist of riser pipe, flange neck or section of a bend, or a combination of the above. The method can be summarised as follows.

A full section of material is mechanically loaded and the test piece filled with the sour environment. The external surface can be ultrasonically monitored and hydrogen probes fitted. Strain gauges are attached to the inside surfaces to monitor the applied load. Data on sulphide stress corrosion cracking (SSCC), hydrogen induced cracking (HIC) and stress oriented hydrogen induced cracking (SOHIC) can be obtained. The effect of galvanic coupling can, if required, be assessed by hydrogen permeation rates, measurement of free corrosion potential, etc.

2. SAMPLES FOR TESTING

The test samples can contain a full circumferential weld which should be positioned at the mid-length of the test piece. In order to retain the residual stress produced during manufacture and welding, the length of the test pipe must be equal to, or larger than, the diameter.

Generally, a single ring is sufficient for testing. The sample should be typical of the as-delivered product and the weld should be made under field conditions or as near a simulation as possible, i.e. the approved welding procedure should be followed.

If weld repair procedures are to be included, then the position should be clearly marked on the outside surface of the sample so that the applied load can be aligned accordingly.

The ends of the section should be machined to provide clean, flat surfaces so that these can be later sealed to form a gas-tight fit.

3. ULTRASONIC INSPECTION

Prior to the section being prepared for test, the external surface should be 100% inspected using the Ultrasonic Test Procedure detailed in Appendix A. Briefly, the section is inspected using a compression probe and shear probes of angles 45°, 60° and 70°. All indications are recorded. This technique is very sensitive and the evidence of pre-test indications should not be taken as indicative of problems. The purpose of this inspection is to provide a 'fingerprint' which will enable a quantitative comparison to be made with later inspections and to avoid failure of a specimen by considering pre-existing indications to have been produced during the test.

It is extremely important to note that the couplant used for the ultrasonic inspection must be silicon free. Silicon compounds/greases are very detrimental to strain gauge application and can cause errors in load monitoring (see Section 5).
4. SURFACE PREPARATION

Usually, an internal surface preparation of grit blasting to Sa 2½ is undertaken using new spherical grit. The grit must not be recycled. However, other surface finishes, such as wire brushing to ST3 can be used by agreement with the Clients.

In order to avoid flash rusting of the cleaned surface, after completion of grit blasting or other surface preparation, the ring sample should be loaded and sealed as soon as possible or stored under a dry atmosphere.

5. SAMPLE LOADING

The ring sample is loaded by mechanical jacking as illustrated in Figure 1. To monitor the load and determine the stress duration, strain gauges are attached to the internal surface, ref. Appendix B.

5.1 POSITION OF MAXIMUM LOAD

Prior to actually loading the sample, the two positions of maximum applied stress must be selected. Two criteria are generally used:

1. The area adjacent to the seam weld should be at maximum stress, or

2. Any ultrasonic indications found in the girth weld or weld repair should be at the position of maximum stress.

It is therefore useful to consider these points prior to commencing the test as it is possible for the repair area in a girth weld to be positioned 180° from a seam weld, in which case all the critical areas can be tested simultaneously.

It is common practice when pipe lengths are welded together, that the two pipe seam welds are a minimum of 30° apart. For efficient testing, placing the seam welds 180° apart is useful as both seams can then be positioned at the location of maximum stress. This is warranted if the two sections are in some way different. If the sections are identical, a standard 30° (+) spacing should be made. Appendix B provides details of the strain gauging technique and also shows the various combinations of ring samples which can be tested.

5.2 STRAIN GAUGING

A detailed procedure for strain gauging is included as Appendix B. The procedure covers eight categories of ring sample, from seamless pipe, spirally welded pipe to a girth welded sample of unequal wall thickness.

In summary, strain gauges are attached at the positions of maximum stress, with other strain gauges positioned to monitor the stress distribution. It is essential that the guidelines in Appendix B are followed in order that inaccurate loading does not occur. In addition to single element gauges, several T gauges are used in order that compensation for Poisson Effect can be made.

Appendix B also contains an example format for reporting the strain gauging and loading data.
5.3 LOADING LEVELS

It is common industry practice to use a specified load level of, for example, 72% specified minimum yield strength (SMYS) for full ring samples. However, this is not mandatory and was selected originally as offshore design codes permitted a maximum 72% SMYS to be used. The set load level will, therefore, depend upon the individual requirement. For instance, land lines would generally be tested at lower levels. The level to be used should be agreed with the Client.

5.4 LOADING TECHNIQUE

The actual loading is undertaken by using a turnbuckle arrangement and two load distribution blocks as shown in Figure 1. The turnbuckle consists of a barrel with a left and right handed thread bore into which two sections screw with the appropriate thread. Ballistic threading is recommended. The load distribution blocks should be non-deflective, i.e. the load should be evenly distributed without the blocks actually bending.

The face of the distribution block which fits against the ring section must be profiled preferably to fit the ring section. A range of blocks will be required if a number of different diameter pipes are to be tested.

After the two loading blocks and turnbuckle are in position and the strain gauges are zeroed, loading then commences. For thin walled ring sections, the load can be applied manually by turning the centre section of the turnbuckle. For thicker sections, a hydraulic jack positioned under but as near to the turnbuckle as possible should be used. In the latter case, as the load is applied, the turnbuckle is tightened and locked when the required stress level is reached. The hydraulic jack is then released. It should be noted that when using a hydraulic jack, the stress level will drop slightly when the jack is released, therefore, a higher stress level may have to be attained before release so that the final relaxed stress level is as required. Care should be taken to avoid excessive load increases and small increments should be used, e.g. 5%.

Once the load has been applied, data from all the strain gauges should be recorded and converted into % SMYS. The ring sample should be left for a minimum 30 minutes to ensure no relaxation or settling takes place. If this does occur, then the load should be corrected. When the final level is achieved, the strain gauges are removed and the gauge areas cleaned and degreased. Any other contaminated areas should also be cleaned and degreased.

6. CELL CONTAINMENT

The loaded ring sample should be made into the test sample by fitting gas tight lids/seals to each end. There are various methods to achieve this and any method meeting the following criteria can be used.

1. The materials used for the lids and seals must not contaminate the test solution and extensive use of vulcanised rubber should be avoided.
2. The lids and fittings must not be so rigid as to contribute to the pipe rigidity, for instance, a welded steel plate should not be used.
3. The material must also be strong enough to withstand the small gas pressure above the liquid environment.
The recommended procedure is to use transparent acrylic sheets, minimum thickness 12 mm with natural rubber gaskets. These are attached by drilling and tapping the ring sample and bolting the lids to the pipe. The lid can be easily drilled to provide sampling and access points, etc. In addition, the lid, being transparent, allows visual checking of solution levels, etc.

After the section has been made into the test cell it can be moved into the safety enclosure* or restricted area.

The ring section should then be purged with an inert gas to protect the clean inner surface and to remove oxygen prior to filling with the test solution.

7. HYDROGEN PERMEATION CELL MONITORING

It is desirable, although not mandatory, that hydrogen permeation cells are attached to full ring tests. Hydrogen permeation cells are an option which should always be considered as the data is extremely valuable in test evaluation. There are several advantages of measuring the hydrogen flux, i.e:

- Comparison can be made with field data (if available).
- Comparison can be made with existing data.
- Effect of coupling on hydrogen permeation can be assessed.

If hydrogen cells are to be fitted, they should be attached after loading and cell containment. For single material ring tests a single cell attachment is sufficient. For girth welded full rings of differing materials, two cells are required. All cells should be fitted in areas of low applied stress as the presence of such cells inhibits ultrasonic inspection of these areas.

Various hydrogen permeation cells are available. A liquid electrolyte cell using a palladium plated steel surface has been found to yield reliable test results. The cells can be attached by straps or, if attached in areas of low applied stress, shallow drilling and tapping of the ring can be undertaken.

8. TEST ENVIRONMENT

There are a number of environments which can be used for the full ring test:

a. NACE TM0177
b. CAPCIS Solution pH 3.2
c. Field design condition

The NACE TM0177 solution is considered the most severe. The initial pH is between 2.7 and 2.9 and will eventually rise to approximately 4 by the end of the 30 day test period.

After extensive study during the Joint Industry Sponsored Project, the CAPCIS solution has been shown to be more pH stable. The CAPCIS solution is NACE TM0177 solution heavily buffered to pH 3.2 by addition of acetic acid/sodium acetate.

The third option is to use the design field conditions as the test environment. This may require solution simulation modelling to be undertaken. [If a pipeline is to be operated at

* Conducting test work with H₂S is inherently hazardous and a secondary containment system is highly recommended (see Health and Safety Note section).
known levels of H₂S, CO₂, Cl⁻, temperature and pressure, a solution representing worst case conditions can be modelled at 24°C and 1 bar pressure by correct dosing of H₂S and pH adjustment.

The chemical requirements of both solutions are given in Appendix C.

9. TEST DURATION AND SOLUTION MONITORING

Unless otherwise agreed, the full ring test duration is 30 days. If the test environment has been reduced in severity from NACE TM0177/CAPCIS solution, extended test duration may be considered.

The H₂S concentration in solution should be checked regularly and maintained at 2300ppm or greater. The H₂S analysis is very important and the technique recommended is included in Appendix D. The analysis should be undertaken daily until the recommended H₂S level is reached and every five days thereafter until completion of the test. All data should be recorded.

The full ring sample should be controlled at a temperature of 24°C (75°F) ± 3°C (4°F) which is best undertaken by fitting heating tape around the base of the test sample and controlled by a thermocouple positioned mid-depth within the test piece. For small diameter samples, an immersion heater with calibrated control can be used.

10. TEST PROCEDURE

After ultrasonic inspection, loading, sealing and purging with inert gas, the test environment can be introduced. A saline solution containing 5% sodium chloride in distilled or deionised water which has been deaerated previously to a level of 100 ppb or less oxygen is prepared in an inert tank. This is used as a basis for the test solution which can be chosen from the following alternatives:

a. NACE TM0177 solution - 50 g sodium chloride, 5g acetic acid, 945 g distilled water
b. CAPCIS solution - 50g sodium chloride, 50g acetic acid, 900 g distilled water. The pH is adjusted to a value of 3.2 ± 0.1 by addition of sodium acetate.
c. A solution to represent field conditions, in which case, the pH should be controlled prior to the introduction of the mixed gas.

Before filling with this solution, the test piece should be checked for leaks. If the test piece is gas tight the prepared solution is transferred from the mixing tank to the test piece under a blanket of nitrogen.

The H₂S gas should then be introduced into the cell. Continuous bubbling is required using an open ended, 5mm or greater diameter tube is recommended. Fritted end tubes are not recommended as they are liable to blockage by corrosion product.

The H₂S level in solution should be measured in accordance with the procedure given in Appendix D. When the H₂S level reaches or exceeds 2300 ppm level the test is deemed to have commenced. This level should be reached within 24 hours.

* On line monitoring by ultrasonic and hydrogen flux measurements may be used to indicate if an extended test duration is required.
11. ON-LINE MONITORING

The following inspections should be undertaken during the test exposure.

a. Ultrasonic inspection, reporting results every seven days ± 2 days, see Appendix A.

b. H₂S content in solution analysis every 5 days after the 2300 ppm level has been attained.

c. If hydrogen permeation cells are attached a continuous reading at, say, every 15 minutes, should be recorded.

d. The temperature, gas flow and general condition of the test should be recorded twice daily.

An example of a test record is provided in Appendix E.

12. TEST CESSION

After the full ring test has completed the agreed exposure period, the section is drained and unloaded. It is recommended that the test solution with is aerated (preferably with oxygen) before draining. A final ultrasonic inspection is then undertaken and all indications recorded. If required, all indications may be characterised metallographically.

13. REAGENTS

The solution shall be made up in distilled or deionised water of a quality equal to or greater than ASTM Type IV (ASTM D1193).

The inert gas used for deaeration shall be of high purity. Nitrogen is generally used, however other inert gases, such as argon, can be employed.

The gases, chemicals and solvents used shall all be of high purity - 99.5% or better.

14. REPORTING

The following data shall be reported:

Test conditions and running as Form 1. (Appendix E)

Pipe dimensions, grade and loading as Form 2. (Appendix E)

Ultrasonic inspection records as specified by the authority undertaking the inspection. The minimum level of reporting as per Appendix A, Section 8 shall be used as a mandatory inspection level.

Metallographic inspection of indications shall be described and evaluation undertaken.

A summary report, detailing pipe dimensions, grade, loading, H₂S levels throughout the test and dates of ultrasonic inspections is recommended, see Appendix E.

* This inspection generally cannot be undertaken on small diameter pipes which have been externally clamped.
15. ACCEPTANCE CRITERIA

The following criteria apply to environments (a) and (b) but not (c) (see Section 10).

15.1 HIC

A crack area ratio of 5% measured by ultrasonic techniques shall be acceptable. Levels greater than this shall be open to discussion. If the cracks are laminar with no stepwise component, a level of 15% can be accepted*.

15.2 SCC

No SCC cracks greater than 0.5 mm in depth (characterised as cracking not pitting) to be allowed.

15.3 SOHIC

The evidence and growth of SOHIC must be confirmed by metallographic inspection. If SOHIC is proven, then the material must be deemed to fail.

If the cracking level obtained is 'borderline', a fracture mechanics study must be undertaken to ascertain if the exhibited cracks are stable under continued hydrogen charging conditions. This analysis will confirm acceptance or rejection of the material under test.

16. MODIFIED TECHNIQUE FOR USE WITH SMALL DIAMETER RING SECTIONS

The full ring test procedure can be applied to ring sections 18" diameter or greater. A modified technique has been developed for smaller diameter sections and is applicable to sections of 16" diameter or less.

It is generally accepted that in sour service testing there is a minimum surface area to volume ratio which should be achieved. This is nominally 5 ccs to 1 cm² of surface. If small diameter sections are to be examined this ratio may not be achieved due to the surface area of the turnbuckle and blocks. Therefore, a modified loading technique is recommended in which the ring section is externally squeezed as shown in Figure 2.

With the exception of the loading method all other parameters of the full ring test remain unchanged.

For very small diameter sections, i.e. 6" diameter or below, it is advisable to have a separate reservoir of test solution and slowly circulate the solution around the test piece by means of a peristaltic pump. This ensures that sufficient volume/surface area ratio is achieved.

Note: The area of ultrasonic inspection is limited due to the presence of the external clamping system.

* For internally loaded test pieces, the area occluded by the load distribution blocks is not taken into consideration.
17. ACKNOWLEDGEMENTS

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Strain Measurement Services Ltd.
18. RELEVANT LITERATURE


10. Provou, Y., Bennett, C., Brown, A., Popperling, R., & Pontremoli, M., "Full Scale Tests in Liquid and Gaseous Environments and Laboratory Tests to $H_2S$ Induced Environmental Fracture of Pipeline Steels and Welds".


EXPLANATORY NOTES ON TEST METHOD

a. The girth welding of any section should be undertaken within the timescale of a field operation and, if possible, full radiography should be made available for comparison to the pre-test ultrasonic inspection.

b. Oxygen must be excluded from the test solution and subsequent test. Oxygen ingress can increase the corrosion rate substantially and also reduce the hydrogen ingress into the sample. If there is evidence of oxygen contamination, i.e. a sudden drop in H2S concentration, precipitation of sulphur, the test should be stopped and re-run.

c. The materials used for cell containment must not affect the test solution. Therefore, natural rubber compounds and inert plastic is recommended. Pre-treated clear acrylic sheet is highly recommended for the lids.

d. Large volumes of test solution are required, for example:

<table>
<thead>
<tr>
<th>Diameter</th>
<th>Litres</th>
</tr>
</thead>
<tbody>
<tr>
<td>30&quot;</td>
<td>300</td>
</tr>
<tr>
<td>36&quot;</td>
<td>500</td>
</tr>
<tr>
<td>46&quot;</td>
<td>1000</td>
</tr>
</tbody>
</table>

At the end of the test, the solution should be purged with nitrogen, air or oxygen prior to removal. There are various methods to accomplish this. If facilities are available to pump out 'live' solution, the test piece should be purged with nitrogen before removing the lids as significant amounts of H2S can still be contained within the cell.

e. Galvanic Coupling

During development and in a number of tests it has been noted that a galvanic couple can be produced when two sections of pipe from different sources are welded together to form the test piece, for example pipe/bend, pipe/flange, pipe A/pulse B. It is therefore useful to note the relevant potentials of each section by inserting a Luggin probe through the lid and measuring the free corrosion potential along the length of the test specimen. These data are particularly useful when the two half sections appear to behave differently.

A typical potential trace is illustrated in Figure 3.

* New acrylic sheet should be pretreated with a 50% acetic acid solution to seal the surfaces by swabbing.
Figure 1: Full Ring Test Using Internal Loading Technique

Figure 2: Modified Full Ring Test Using External Loading Technique
Figure 3: Typical Example of Potential Change on a Girth Welded Sample
ILLUSTRATED SUMMARY OF THE FULL RING TEST PROCEDURE

The test method can be summarised in a series of steps as listed below, together with illustrations which assist understanding.

The illustrations are taken from various projects and do not represent the material from any particular company.

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
<th>Figure No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Machine ring ends to provide clean flat ends</td>
<td>S1</td>
</tr>
<tr>
<td>2</td>
<td>Grit blast to required finish</td>
<td>S2</td>
</tr>
<tr>
<td>3</td>
<td>Full pre-test ultrasonic inspection</td>
<td>S3</td>
</tr>
<tr>
<td>4</td>
<td>Strain gauge inside surface</td>
<td>S4</td>
</tr>
<tr>
<td>5</td>
<td>Apply internal load</td>
<td>S5</td>
</tr>
<tr>
<td>6</td>
<td>Convert ring into test cell</td>
<td>S6</td>
</tr>
<tr>
<td>7</td>
<td>Position in secondary safety tank</td>
<td>S7</td>
</tr>
<tr>
<td>8</td>
<td>Affix hydrogen permeation cells</td>
<td>S8</td>
</tr>
<tr>
<td>9</td>
<td>Purge ring with nitrogen</td>
<td>S9</td>
</tr>
<tr>
<td>10</td>
<td>Fill ring with previously deaerated solution</td>
<td>S10</td>
</tr>
<tr>
<td>11</td>
<td>Charge with H₂S gas, monitor H₂S level by sampling</td>
<td>S11 - HIC</td>
</tr>
<tr>
<td>12</td>
<td>Ultrasonically inspect at approximately 7 day intervals</td>
<td>S12 - weld SSCC</td>
</tr>
<tr>
<td>13</td>
<td>After 30 days, drain ring and unload</td>
<td>S13 - HAZ soft zone</td>
</tr>
<tr>
<td>14</td>
<td>Final ultrasonic inspection</td>
<td>S14 - SOHIC</td>
</tr>
<tr>
<td>15</td>
<td>Produce hydrogen permeation data</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Metallographically examine any significant ultrasonic indications. There are four main types of crack illustrated in Figures S11 to S14</td>
<td></td>
</tr>
</tbody>
</table>
FIGURE S1. Ring machining to provide flat ends.

FIGURE S2. Ring machined and grit blasted.
FIGURE S3. Ring strain gauged.
FIGURE S4a. Application of internal load

FIGURE S4b. Application of external load.
FIGURE S5. Conversion of ring into test cell.

FIGURE S6. Hydrogen permeation cell attachment.
FIGURE S7. On-line ultrasonic inspection.

FIGURE S8. Full ring after test.
FIGURE S9. Example of ultrasonic indications after test.
FIGURE S10. Example of recorded hydrogen permeation data.
FIGURE S11. Typical HIC crack.
FIGURE S12. Typical weld SSCC.
FIGURE S13. Typical soft zone crack.
GLOSSARY OF TERMS

Anodic
The electrode or electrode area at which the oxidation (electron producing) process occurs.

Cathodic
The electrode or electrode area at which the reduction (electron consuming) process occurs.

Free Corrosion Potential
The naturally occurring potential adopted by a metal undergoing corrosion.

Galvanic Coupling
This occurs when two or more dissimilar metals or alloys of different chemical compositions in contact in a corrosive fluid leading to an increased dissolution of the anodic metal or alloy and a corresponding cathodic protection of the more cathodic component which then exhibits increased hydrogen evolution.

Girth (Circumferential) Welding
A butt weld joining one pipe to another (or bend or flange)

Hardness
Resistance of metal to plastic deformation, usually by indentation.

Heat Affected Zone (HAZ)
That portion of the base metal that was not melted during brazing, cutting or welding, but whose microstructure and properties were altered by the heat of these processes.

Hydrogen Embrittlement
The action of hydrogen to cause loss of ductility in a metal. Generally, hydrogen atoms are attracted to grain boundaries and slip plane movement is reduced.

Hydrogen Flux
The rate of hydrogen flow per unit area through a material.

Hydrogen Induced Cracking (HIC)
Cracking caused by atoms of hydrogen concentrating at discontinuities within the steel to form hydrogen gas. The resultant gas pressure induces cracking. (Also called hydrogen pressure induced cracking (HPIC), stepwise cracking, blister cracking (HIBC).)

Hydrogen Permeation
Process of atomic hydrogen diffusion through a metal.

Longitudinal Weld
A straight weld running along the axis of a pipe.

Low Alloy Steel
Steel with a total alloying element content of less than about 5% but more than specified for carbon steel.

Measured Strain ($e_1, e_2, e_3$)
The surface strain as measured by various techniques in one or more of three known directions at the surface.

Microstructure
The structure of a metal as revealed by the microscopic examination of a suitably prepared specimen.

Normal Stress ($\sigma$)
Normal stress ($\sigma$) equates to the applied force per unit area existing on any object as a result of external mechanical or thermal influences acting in that direction.

Partial Pressure
The partial pressure of each component in a gas mixture is
equal to the total pressure multiplied by its mole fraction in
the mixture. For an ideal gas, the mole fraction is equal to
the volume fraction of the component.

Plastic Deformation

Permanent deformation caused by stressing beyond the
elastic limit.

Poisson's Effect

Any component subjected to loading in one direction
causing extension or compression in that direction will
experience tangentially, a lesser opposing compression or
expansion. This is known as the Poisson Effect.

Poisson's Ratio ($\nu$)

This is a dimensionless material constant (approximately
0.3 for steel) and is given by the ratio of
contraction/expansion per unit length tangential to the
direction of loading over the expansion/contraction per unit
length in the direction of loading.

Principal Strain ($\varepsilon_{\text{p}}$)

The maximum and minimum strain levels existing at a point
on the test surface acting at 90° to each other as calculated
from measured strain values.

Principal Stresses ($\sigma_{\text{p}}$)

The maximum and minimum stresses existing at a given
point on the surface of an object.

Principal Stress Directions
($\varnothing_{\text{p}}$)

The directions in which maximum and minimum principal
stresses exist relative to a given axis of the object.

Residual Stress($\sigma_{\text{res}}$)

Stress present in a component free of external forces or
thermal gradients.

SAW Pipe

The tubular product manufactured by forming from strip or
plate and welding the abutting edges by addition of filler
metal by the automatic submerged arc process.

Seamless Pipe

Pipe manufactured without a seam weld.

SOHIC

Stress oriented hydrogen induced cracking.

Sour Environment

Any environment where hydrogen sulphide exists in the
presence of water.

Spiral Weld

A weld running spirally around the circumference of a pipe.

Strain ($\varepsilon$)

This is a dimensionless ratio of the change in length per unit
length (mm/mm, ins/ins) and is normally expressed in parts
per million ($\varepsilon \times 10^6$) of microstrain ($\mu$e).
<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
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<tr>
<td>Specified Minimum Yield Strength</td>
<td>This relates to the minimum 0.2% yield strength permitted for a given grade of material, e.g., API 5L Grade X60 steels would not be permitted to have an 0.2% yield strength below 60,000 psi or 414 MPa.</td>
</tr>
<tr>
<td>Strain Gauges</td>
<td>A device the electrical resistance of which changes in proportion to applied strain.</td>
</tr>
<tr>
<td>Sulphide Stress Corrosion Cracking</td>
<td>Brittle failure by cracking under the combined action of tensile stress and corrosion in the presence of water and hydrogen sulphide.</td>
</tr>
<tr>
<td>Tensile Strength</td>
<td>In tensile testing, the ratio of maximum load to original cross-sectional area (reference ASTM A370). Also called 'ultimate strength'.</td>
</tr>
<tr>
<td>Tensile Stress</td>
<td>The net tensile component of all combined stresses - axial or longitudinal, circumferential or 'hoop' and residual.</td>
</tr>
<tr>
<td>Ultrasonic Inspection</td>
<td>Inspection of material by ultrasound for the presence of defects.</td>
</tr>
<tr>
<td>Welding</td>
<td>The joining of two metallic materials by fusion.</td>
</tr>
<tr>
<td>Yield Strength</td>
<td>The stress at which a material exhibits a specified deviation from the proportionality of stress to strain. The deviation is expressed in terms of strain either by the offset method (usually at a strain of 0.2%) or the total-extension-under-load method (usually at a strain of 0.5%) (reference ASTM A370).</td>
</tr>
<tr>
<td>Young's Modulus of Elasticity (E)</td>
<td>Young's Modulus is the relationship between stress and strain within the limits of elastic behaviour ( E = \frac{\text{Stress}}{\text{Strain}} ). Valid only in the direction of loading.</td>
</tr>
</tbody>
</table>
APPENDIX A

ULTRASONIC EXAMINATION OF PIPE, PLATE AND WELDS DURING ACCELERATED LABORATORY TESTS

PROCEDURE NO. NDT-028
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<td>6.4 SHEAR WAVE - WELD VOLUME EXAMINATION</td>
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<td>9.</td>
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</table>
1. INTRODUCTION

Pipelines transporting hydrocarbon fluids could be prone to develop hydrogen pressure induced cracking (HPIC), this normally occurs in the mid-wall section of the pipe plate, and through a series of steps, cracking can become surface emerging.

Cracking also occurs in the circumferential butt weld, usually transverse, and eventually becomes surface emerging.

The longitudinal weld can develop toe cracks usually emanating from the internal surface.

The Non-Destructive Testing (NDT) method considered most appropriate for early crack detection is ultrasonic. As the cracking in the plate is predominantly within the mid-wall and normal probe scan is the main method of scanning, the operator must be able to discriminate between HPIC and lamination using shear scan.

2. PURPOSE

This procedure defines the ultrasonic method and the requirements to be followed for the inspection of pipe, plate and weld during an accelerated operating test.

3. GENERAL REQUIREMENTS

3.1 REFERENCES

The current issue of the following documents will be used in conjunction with this procedure:

   Part 2: 'Electrical Performance'

3.2 PERSONNEL

3.2.1 NDT Engineers will be qualified to one or more of the following standards specified in paragraphs 3.2.2 and 3.2.3 below:
3.2.2 PCN Ultrasonic Practitioner Level 2
3.2.3 ASNT-TC-1A Ultrasonic Tester Level II
3.2.4 All personnel responsible for conducting tests shall have natural or corrected near distance acuity of eyesight such that they can read a minimum Jaeger number 1 letters (or equivalent British N sizes) at a distance of not less than 300 mm.

3.3 EQUIPMENT

3.3.1 Ultrasonic flaw detectors meeting the requirements of BS 4331 Part 1 will be used e.g. Krautkramer Type USM2, USD10 or USN50.

3.3.2 Instrument Facilities

The instrument will have the facility for both single and double transducer operation. The instrument will be capable of presenting an 'A' scope display on the integral cathode ray tube time base.

The instrument shall be fitted with an integral amplitude gain or attenuator control. The control will cover a useful range that is compatible for the particular work to be tested. The control function will have an accuracy of ± 1 dB over any 20 dB range with steps no greater than 2 dB.

3.3.3 Ultrasonic probes to be used will comply with the test requirements for the relevant ESI standard.

All probes will have a unique number traceable to the certificate issued by the manufacturer stating that they meet the above requirements. All probes will be compatible with the ultrasonic flaw detector.

Only probes which have been made and supplied by a manufacturer who verifies by certificates that his manufacturing and testing standards have been evaluated and found to comply with the Quality Assurance requirements of BS 5750 Part 2 will be used.

3.3.4 Compression Probes

Single and/or combined double crystal compression wave probes will be used. They will have a crystal size ranging between 5 - 10 mm and a frequency in the range of 4 - 15 MHz.

Exact probe details to be specified in the individual report/technique sheet.

3.3.5 Shear Wave Probes

Single and/or combined double crystal 45°, 60° and 70° shear probes will be used. They will generally have a crystal size of 10 mm and a frequency in the range of 4 - 5 MHz.

Exact probe details to be specified in individual report/technique sheets.

3.3.6 Calibration Reference Blocks

The following calibration and reference blocks will be available at the time of testing:

i. BS2704 A4 Block (IIW-V2)
3.3.7 Flaw Location Aids

Suitable flaw location equipment such as slides will be available and used at the time of testing.

3.3.8 Couplant

The couplant used will be SURTEST UCA-1 or UCA-2. The couplants may be used provided they do not adversely affect the test results of the product.

3.4 SURFACE CONDITION

3.4.1 All surfaces from which scanning is to be carried out will be prepared such that satisfactory acoustic coupling can be achieved for the full scan distance. To achieve this, the scanning surface will be free from loose oxide scale, weld spatter and other surface irregularities.

3.4.2 The entry and back surfaces of the component will be sufficiently smooth and flat to maintain a first backwall echo amplitude of greater than 50% full screen height while scanning an area which does not contain significant reflectors.

3.4.3 The scanning surface finish of the item under examination shall be 6.3 micrometre Ra (250 microinches CLA) or better.

3.5 SCOPE OF EXAMINATION

3.5.1 The ultrasonic examination shall be performed on the pipe prior to going into service and whilst in service at regular intervals.

3.5.2 The weld volume, heat affected zone and adjacent parent material will be scanned using compression wave techniques.

3.5.3 The entire weld volume including the heat affected zone and any laminar indications observed in the parent plate will be examined using shear wave technique.

4. IMPLEMENTATION

4.1 ULTRASONIC FLAW DETECTOR/PROBE COMBINATION PERFORMANCE CHARACTERISTIC CHECKS

4.1.1 All checks will be carried out in accordance with BS4331 Part 1. The following minimum routine checks shall be carried out at the beginning of each day or each separate examination.
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Method</th>
<th>Tolerance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Time base linearity</td>
<td>BS4331:Part 1</td>
<td>As per BS4331:Part 1</td>
</tr>
<tr>
<td>2 Linearity of equipment gain</td>
<td>BS4331:Part 1</td>
<td>As per BS4331:Part 1</td>
</tr>
<tr>
<td>3 Probe Index</td>
<td>BS4331:Part 1</td>
<td>If greater than ±1 mm from previous remark and record</td>
</tr>
<tr>
<td>4 Probe Beam Angle</td>
<td>BS4331:Part 1</td>
<td>If greater than ±1° from previous measurement remark and record</td>
</tr>
<tr>
<td>5 Probe Beam Profile</td>
<td>BS4331:Part 3</td>
<td>Any side lobes should be at least 20 dB less intense than the main lobe</td>
</tr>
<tr>
<td>6 Probe Beam Squint (single crystal probes)</td>
<td>If excessive squint is suspected during tests then investigate by method of BS4331:Part 1 para 11 or Part 3 para 13.</td>
<td>Less than 2°</td>
</tr>
</tbody>
</table>

5. EXAMINATION PROCEDURE

Unless otherwise requested, the weld examination will be performed in accordance with BS3923.

5.1 DETERMINATION OF SCANNING SENSITIVITY - COMPRESSIONAL WAVE

5.1.1 The scanning sensitivity is derived from the second backwall echo set at full screen height obtained from an imperfection free part of the pipe.

5.1.2 Evaluation of indications will be performed if they exceed 15% threshold of the base line and if the greatest dimension is less than the probe diameter, then it is termed a 'Point Reflector'. Position from datum, length and depth recorded. Also indication signal height expressed in either percentage or decibels can be recorded.

5.1.3 Alternative method if requested, using standard reference blocks containing flat bottomed/side drilled holes at a depth nominally equal to or greater than the product thickness, at one half (½) and one quarter (¼) of the product thickness can be used.

5.1.4 A distance amplitude curve (DAC) will be constructed using the blocks, as indicated in the Standard/Code, to determine the reference level.

5.1.5 Should the difference in surface condition between the reference blocks and item under test indicate a possible transfer loss, this should be determined prior to the examination and adjustment be made if the difference exceeds ±2 dB.

5.1.6 Where there is an acoustic difference between the reference blocks and the item under test, an attenuation correction should be made to compensate for the difference.
5.1.7 The scanning sensitivity will be the 'reference level' plus the amount of 'gain' indicated by the Standard/Code.

5.1.8 Evaluation of indications will be performed with due regard to the 'reference level' setting, specified by the Standard/Code with due compensation for any transfer loss/attenuation variations.

5.2 DETERMINATION OF SCANNING SENSITIVITY - SHEAR WAVE

5.2.1 The scanning sensitivity will be determined using the reference blocks as described in Section 3.2.7.

5.2.2 Standard reference blocks containing side drilled holes at a depth nominally equal to or greater than the product thickness will be used.

5.2.3 The maximised signal echo from the side drilled hole at a depth of product thickness is set at full screen height plus 6 dB.

5.2.4 Alternatively a DAC will be constructed using these blocks and if item under test indicates a possible transfer loss, this should be determined prior to the examination and adjustment be made if the difference exceeds ± 2 dB.

5.2.5 Where there is an acoustic difference (attenuation) between the reference block and item under test, this shall be taken into account when determining the size of indications (Reference Level Setting). Measurements will be performed for each dimension and material type.

5.2.6 The scanning sensitivity will be the 'reference level' plus that amount of 'gain' specified by the Standard/Code.

5.2.7 Evaluation of the indications will be performed at the sensitivity setting specified in the Standard/Code with due compensation for any transfer loss/attenuation variations.

6. SCANNING

6.1 COMPRESSION WAVE - BASE MATERIAL EXAMINATION

6.1.1 The entire external surface of the pipe plate will be examined in two directions using compression wave techniques to detect imperfections and also to ascertain the exact wall thickness of the material.

6.1.2 The volume of base material through which shear wave examinations are to be carried out, i.e. an area of 5.5 times the material thickness plus 30 mm on each side of the weld, will be examined using the compression wave techniques to detect imperfections which might interfere with the shear wave examination and also to ascertain the exact wall thickness of the material and locate any variations in the same.

6.2 COMPRESSION WAVE - WELD VOLUME EXAMINATION

6.2.1 The weld volume and heat affected zone will be examined using compression wave techniques where access, surface condition and weld configuration allow in order to ensure complete coverage.
6.2.2 Scanning will be carried out as detailed by the appropriate ultrasonic technique of the Standard/Code which will also detail probes to be used for material and weld examination, scanning methods and positions, test limitations (if any) and other pertinent remarks.

6.3 SHEAR WAVE - BASE MATERIAL EXAMINATION

6.3.1 Scanning of base material will be carried out where imperfections were found by compression wave technique and will be carried out using angle beam search units of at least two different refracted angles. The differences between the angles shall be at least 15°, normally 45°, 60° and 70° refracted angles being used.

The scanning will be carried out to determine whether it is laminar or volumetric imperfections (stepwise cracking).

6.4 SHEAR WAVE - WELD VOLUME EXAMINATION

6.4.1 Scanning of welds will be carried out using angle beam search units of at least two different refracted angles or as specified by the Standard/Code. The difference between the angles shall be at least 15°, normally 45°, 60° and 70° refracted angles being used. The entire weld volume including heat affected zones will be scanned using a full V-patch.

6.4.2 Scanning will be carried out as detailed in the appropriate ultrasonic Standard/Code technique sheet which will also detail probes to be used, scanning methods and positions, test limitations (if any) and other pertinent remarks.

6.5 SCANNING RATE

6.5.1 The scanning rate will not exceed 150 mm per second.

6.6 SCANNING INDEX

6.6.1 Scanning will be carried out ensuring that there is a minimum of 50% overlap of the effective crystal diameter on adjacent scan paths in order to ensure total coverage of the material.

6.7 RECALIBRATION CHECKS AND FREQUENCY THEREOF

6.7.1 Equipment will be calibrated prior to the examination after movement of the equipment, after interruptions in the examination, prior to the evaluation of indications and at equal intervals during the examination with a maximum periodicity of every 30 minutes.
7. ACCEPTANCE AND RECORDING STANDARDS

7.1 As required by the referencing Standard/Code.

7.2 A factual report detailing all indications having a response in excess of the recording level will be submitted to the Client.

8. REPORTING

8.1 A test report will be issued, the minimum content will be as follows:

1. Clients Name and Address
2. Test Location
3. Date of Examination
4. Reference to Ultrasonic Procedure and Technique where relevant.
5. Weld Identification.
6. Quality Plan Identification and Operation number where applicable.
7. Drawing Number where applicable.
8. Surface Condition.
10 Calibration and Reference Block Identification and Dimensions.
11. Couplant.
12. Examination Results together with a sketch, where necessary, indicating the sizes and positions of all recorded defects and all areas which cannot be examined.
13. Datum point. Where the examination is being performed on a specimen at regular monitoring intervals, care will be taken to ensure that the same datum is used for each subsequent examination.
14. NDT Engineers signature, printed name and approval details where relevant.

9. NON-COMPLIANCE

If the NDT Engineer is unable to comply with this procedure, then guidance shall be sought from the Client. Any agreed deviation shall be documented and referenced for NDT Departmental Records.
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**ANNEX A**  **TYPICAL INTERNAL AND EXTERNAL LOAD APPLICATION RIGS FOR USE IN THE CAPCIS FULL RING TEST**
1. INTRODUCTION

This procedural document incorporates the strain gauging technique as a means of pre-tensioning full ring test specimens of 3" to 46" diameter prior to sour service.

It is recommended that the technique described shall be conducted by competent personnel who hold the Diploma of the British Society for Strain Measurement or its equivalent. Persons having attained Part I of the Diploma (competent to apply strain gauges) may be used under supervision of a Chartered Engineer.

2. RING SPECIMENS

Neglecting ring diameters; specimens fall into 8 categories which may be designated as:

1. Seamless specimens
2. Specimens containing a longitudinal weld seam only
3. Specimens containing a spirally wound weld seam only
4. Specimens containing a circumferential weld seam only
5. Specimens having either longitudinal or spirally wound weld seams connected by a circumferential weld seam; wall thicknesses either side of the circumferential weld seam being equal.
6. As in (5) above but with wall thicknesses either side of the circumferential weld seam being unequal
7. Seamless specimens girth welded to specimens containing a longitudinal weld seam; wall thickness either side of the circumferential weld being equal.
8. As in (7) above but with wall thicknesses either side of the circumferential weld seam being unequal.

Each of these cases has to be treated separately with regard not just to strain gauging but also the mode of loading.

3. LOAD APPLICATION

Load application is accomplished by one of two methods depending principally on the diameter of the ring specimen under test.

For rings having a diameter of less than 20" (500 mm), the specimen is loaded externally using the form of loading rig shown in Figure 1 of Annex 1. This takes the form of two substantial loading blocks interconnected by six loading screws that apply and distribute the load evenly. The specimen ring is placed between the loading blocks to achieve peak tensile stress internally at the two points of contact with the blocks.

For ring specimens which are greater in diameter than 20" (500 mm), the typical form of rig shown in Figure 2 of Annex A is utilised. In this rig loading is applied internally using a turnbuckle via two loading blocks. Here, loading is applied 90° and 270° remote from the position of peak internal stress. Due to ring specimen size, initial loading is applied through a
hydraulic jack situated below the turnbuckle; the turnbuckle is then tightened before removing the hydraulic loading.

4. LOADING RIG TREATMENT

Both forms of rig are designed for repeated use. At conclusion of chemical treatment of any ring specimen; any rig component that has been submerged within the treatment area shall be thoroughly wire brushed and, where practicable, submerged in oil until next required. On removal from the oil, the components should be degreased. At no time should components of either form of rig come into contact with copper (Cu) or molybdenum (Mo) greases.

5. SURFACE PREPARATION OF RING SPECIMENS

For the purpose of strain gauge application and subsequent chemical testing, the internal surface of any ring specimen shall be grit blasted to Sa 2½ using new round grit without recirculation. To reduce contamination through oxidation, all surface preparation and subsequent gauge application shall be completed within 6 hours of grit blasting. Alternative surface finishes can be agreed with the Client.

Persons responsible for conducting surface processes on any ring subject to subsequent strain gauge testing shall ensure that all products used in such processes are free from silicon compounds.

All areas intended for subsequent strain gauge application shall be thoroughly degreased using Propan-2-ol or similar degreasing agent.

Gauge positions shall be marked out initially using French chalk with the markings extending approximately 100 mm beyond the gauge position in all directions. An area approximately 25 mm x 25 mm centred on each gauge position shall be lightly ground using a 180/240 grit wheel and then polished using 520/400 grit. This latter operation must be conducted using rotary motion to prevent producing linear stress raisers. Where such positions encroach on weld seams, it shall be ensured that the grinding and polishing extends across the toe of the weld and on to weld metal. Such operations shall be completed using light pressure to reduce introduction of residual stress.

Each gauge position shall then be finally marked out using a 2H grade pencil and the positions additionally treated in the manner described by the gauge manufacturer.

6. STRAIN GAUGES

Strain gauges of the electrical resistance foil type shall be used. Such gauges shall be of 120 Ohm nominal resistance and shall have nominal gauge lengths of 1 mm for ring diameters of 6" or less and 2mm for ring diameters greater than 6". For the purpose of static measurement, the following forms of gauge are recommended:

1. Single element
2. 90° stacked rectangular
3. 45° stacked rosette.

The strain gauges shall be self-temperature compensated appropriate to the ring test material and shall have stability within the range -10°C to +30°C.

Strain gauges shall be applied with one element orientated in the hoop axis of the ring specimen.
The centres of gauge grids will normally be positioned at a nominal distance of 3 mm to 3.5 mm from the toe positions of any welds seams where encountered.

7. STRAIN GAUGE ADHESIVES

The adhesive used in strain gauge bonding to the test surface shall be compatible with the applied gauges. It shall be of the cyano-acrylate type and capable of withstanding strain levels of the order of 2% strain (20000 με).

8. STRAIN GAUGE WIRING

All wiring to strain gauges shall be made up from 3-core, 0.08 mm Cu/PVC sheathed cable and connected to instrumentation using 3-wire quarter-bridge principals.

Principal output wiring shall be connected to composite gauge wiring via suitable tab terminals.

Solders utilised shall be compatible with the applied strain gauges. All soldering shall be free of solder spikes and cold joints and be cleared of any residual flux on completion.

9. STRAIN GAUGE TESTS

All strain gauges shall, immediately following application, be checked with a purpose-designed Strain Gauge Installation Test Instrument to ensure that:

1. Nominal gauge resistance deviation is less than 1%
2. Insulation resistance to earth exceeds 2 kMΩ.
3. An effective bond exists at the gauge glue line.

10. STRAIN GAUGE DATA ACQUISITION

After acceptance of strain gauge tests, the fitted gauges shall be connected to a suitable Strain Gauge Test Instrument. (This, for preference, should be of the data logger form, capable of giving visual output from any selected station in addition to normal printed tape output/computer feed.)

11. STRAIN GAUGE POSITIONS ON FULL RING SPECIMENS (INTERNAL)

Eight forms of ring specimen were described previously. In this section the minimum number of gauges required in order to achieve acceptable pre-tensioning within the agreed bounds of experimental error are described.
CLARIFICATION NOTES

Gauge Preparation and Application

It will be noted that this Procedural Specification gives no mention of gauge preparation or application. It is the user's responsibility to ensure that only qualified personnel are employed in this work (as described previously), such persons already being fully aware of these requirements.

Experimental Errors

There are a number of factors that may introduce errors into the loading system if due care is not taken. These are:

1. Misalignment of the loading blocks along the 90°/270° longitudinal axes of the ring specimen.

2. Misalignment of the turnbuckle across the centreline of the girth weld where present.

3. Off-centre guide cups in the loading blocks for location of the turnbuckle screw heads.

4. The loading blocks should be radiused to match the ring internal diameter to reduce the tendency for blocks to dig into the ring wall and thereby redistribute the overall stresses, over a period days, from loading.

5. Where internal ring wall mis-match occurs, it is essential to produce accurate shimming between the ring wall and loading blocks to prevent redistribution of stresses with time as in (4) above.

6. Misalignment of strain gauges in respect to the ring longitudinal and circumferential axes.

7. Non-attention to differences between instrumental gauge factor settings and the gauge factors of strain gauges used. This includes the use of strain gauges where the stipulated gauge factor is only quoted as 'nominal' and it is recommended that such gauges are not used in full ring testing.

8. Settlement of load distribution about the threads of the turnbuckle following loading will tend to relax load at the loading blocks and, hence, also throughout the ring.

These are the principle areas that may cause serious error and great care must be taken in reducing these to a minimum when undertaking loading of ring specimens using the strain gauge technique.

11.1 SEAMLESS SPECIMENS

Gauges of the 90° rectangular form shall be located as shown in Figure 1, along the central circumference of the ring.
FIGURE 1. Gauge positions for seamless ring specimens.

Where doubt exists as to the position of loading points in relationship to the target (0°) pre-tensioning zone, it may be necessary to apply two single element gauges; one either side of one of the 90° rectangular gauges so that any imbalance can be quickly observed and rectified by repositioning the applied load. These added gauges should be equi-distant from, and within 25 mm of the 90° rectangular gauge and applied in the same circumferential axis.

11.2 LONGITUDINAL WELD SEAM SPECIMENS

Gauges of the 90° rectangular type shall be positioned as shown in Figure 2, on the central circumference of the ring.

FIGURE 2. Gauge positions for ring specimens that contain only a longitudinal seam weld.

In this form of ring specimen, gauges are again located in the central circumferential axis. The target pre-tensioning position (0°) shall lie immediately to one side of the longitudinal seam toe of weld. Again, where there are any doubts as to position of loading points in relationship to the target pre-tensioning zone, then the added single element gauges should be applied in the 180° axis equi-spaced no more than 25 mm either side of the 90° rectangular gauge.

11.3 SPIRALLY WOUND WELD SEAM SPECIMENS

Ring specimens of the spirally wound form may still be encountered and here a combination of 90° rectangular and 45° rosette type gauges is used as shown in Figure 3.
11.4 CIRCUMFERENTIAL WELD SEAM SPECIMENS

Usually confined to ring specimens of small diameter, gauges of the 90° rectangular form are used at positions shown in Figure 4. Doubts may arise as to the position of loading points relative to the target (0°) pre-tensioning zone. Where practicable, additional single element gauges may be placed as shown, but this will depend upon available space for such gauges to be applied at less than 15° either side of the datum.

11.5 CIRCUMFERENTIAL WELD SPECIMENS COMBINED WITH LONGITUDINAL OR SPIRAL WELDS - ALL PLATES OF IDENTICAL WALL THICKNESS

This form of ring specimen has a wide variety of geometries as shown in Figures 5, 6 and 7. In the general case, Figure 5, the longitudinal weld seams may be displaced by between 30° and 180°. In some cases, the secondary weld seam will come into contact with one of the loading beams. In such cases it is necessary to grind back the weld cap of the longitudinal weld seam flush with the internal ring surface.
FIGURE 5. Gauge positions for ring specimens that contain both circumferential and longitudinal weld seams and have an angular gap of between 5° and 175° between longitudinal seams. Gauges are of the 90° rectangular type except for single element optionals.

Should the angular gap between longitudinal weld seams be of the order of 0° to 5° or 175° to 185°, then additional gauging in the target zone (and about 180°) will be necessary as shown in Figure 6.

FIGURE 6. Modified gauge positions for ring specimens that contain both circumferential and longitudinal weld seams and have an angular off-set of <5° or 175° to 185° between longitudinal weld seams.

In the case of the spirally wound specimens containing a circumferential weld seam, gauging as shown in Figure 7 below shall be applied.
11.6 CIRCUMFERENTIAL WELD SPECIMENS COMBINED WITH LONGITUDINAL SPIRAL WELDS - PLATES OF UNEQUAL WALL THICKNESS

Occasionally, risers and similar sections come under test and in such cases, the thickness of ring sections either side of the circumferential weld seam can vary considerably.

In most cases with this form of girth juncture, the ring wall thickness difference is taken upon the internal bore diameter. Hence the internal ring wall is stepped. In some cases this step is unequal which gives rise to different widths of gap behind the loading blocks at the larger inside diameter ring. It is essential that packer shims of correct thickness be produced for behind each loading block to ensure an even distribution of load throughout the ring assembly.

11.7 SEAMLESS RINGS COMBINED WITH LONGITUDINAL WELD SPECIMENS

These are essentially similar to the case just described. In the case of rings having similar thickness refer to Figure 8 and omit or optionally use gauges 3, 4, 5, 8, 9 and 10 using single element gauges is included. For rings of dissimilar thickness employ Figure 8 without change.
12. RING PRE-TENSIONING STRESS/STRAIN CALCULATIONS

These are principally as shown on the specimen data record sheet included at the end of this Procedural Document\(^1\). It has been shown that the strain at the 0° and 180° axes can increase with time under constant load by as much as 2% where the pre-tensioning load is set at 72% specified minimum yield strength (SMYS). Where higher pre-tensioning values are set, this factor should be taken into consideration.

The actual loading level shall be defined by the Purchaser and Test Agency bearing in mind ultimate design requirements. In general, however, load levels fall into the following range, dependent upon final use:

- 30% On land
- 60% Risers
- 72% Offshore

13. REPORTING OF RING SPECIMEN LOADING

Principal dimensional information, together with material properties of the ring specimen undergoing loading will be provided. Such information shall be produced on a Full Ring Testing - Loading Data Sheet. The form also details the required pre-tensioning level and provides for the required calculation of strain that will be required to achieve this. An opened-out plan of the internal ring surface is provided so that weld detail can be outlined, together with gauge positions and numbering. A section is provided so that all strain gauge readings can be tabulated, together with final calculations of principal hoop strain and achieved stress levels. Finally, any procedural deviations shall be recorded.

This form should be accompanied by copies of certification for applied strain gauges. An example is shown in Appendix E.

14. SECONDARY TESTING

On occasions it is necessary to re-test a ring specimen at a higher percentage of SMYS. To carry out such a procedure requires the complete off-loading of the ring, grit blasting and the re-application of strain gauges as given in earlier sections of this document. However, on off-loading, it is usual to find some degree of permanent set in the ring, indicating the introduction of permanent residual strain. The degree of residual surface strain must be evaluated prior to an re-loading. It is unlikely that any significant residual strain will be present in the longitudinal axis of the ring and, therefore, single element strain gauges may be used at all positions originally gauged during loading. Surfaces should, of course, be thoroughly cleaned and prepared as described in earlier sections prior to gauge application.

On removal of the load, the strain values obtained at each gauge should be noted and in final re-loading, such values removed from the calculated strain levels required to attain the new

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\(^1\) The data record sheet provided is 'tentative' only (awaiting comments/appraisal) and at present test data and diagrams of the ring and strain gauging are provided in accord with individual test needs.
percentage SMYS. Separate Test Result Sheets should be produced for both the off-loading and re-loading phases when issuing the Final Report.
ANNEX A

TYPICAL INTERNAL AND EXTERNAL
LOAD APPLICATION RIGS
FOR USE IN THE CAPCIS FULL RING TEST
Figure 1. External loading blocks used for ring specimens below 20" (508 mm) in diameter.
FIGURE 2 Plan and cross-sectional view on one face of internal loading rig adaptable to ring diameters of 20" to 30".

Loading Rig for the "Full Ring" Test

DWG. NO. C1049-1
CHEMISTRY OF TEST SOLUTIONS

Note: As acetic acid (and thio compounds such as thioacetic acid) are volatile, care must be taken not to lose them during deaeration.

Standard NACE TM0177-90 solution compositions:

- sodium chloride 50g
- acetic acid 5g
- distilled water 945g

Method Of Preparation

Distilled water is deaerated with nitrogen for at least 24 hours. Into this water the correct amounts of sodium chloride and acetic acid are added. These reagents are then dissolved and dispersed into the water with as little turbulence as practically possible. The solution is then deaerated with a slow bleed of nitrogen for thirty minutes.

The pH of the resultant solution should be 2.7 - 2.9.

CAPCOIS solution composition:

- sodium chloride 50g
- acetic acid 50g
- distilled water 900g

Method Of Preparation

As above.

The initial pH of this solution is lower than that of NACE solution due to the larger amount of acetic acid, but its pH can be raised by sodium hydroxide or sodium acetate additions to a level of 3.2.

Saturation with H₂S

The solutions are then saturated with H₂S. This is best achieved in situ in the test cells or pipes. The temperature of the solution is maintained at 24°C ± 3°C throughout the test period.
ANALYSIS OF TEST SOLUTION

IODIMETRIC TITRATION PROCEDURE

A sample of H₂S containing solution is added to iodine solution. The sulphide is oxidised to sulphur by the iodine and the residual iodine is titrated against 0.05 N sodium thiosulphate. This enables calculation of the sulphide content.

1. Accurately measure the volume (about 10 ml) of the sample solution into a 250 ml conical flask. A measuring cylinder (not a pipette) must be used for this.

2. Add the sample to a flask containing 10 ml of the standardised 0.1 N iodine solution and mix thoroughly.

3. Add about 1 ml of 10% hydrochloric acid.

4. Titrate by adding 0.05 N sodium thiosulphate by means of a burette until a pale straw colour is reached.

5. Add about 1 ml of starch solution and mix to produce a dark blue colour. Then titrate until this blue colour is just discharged.

\[
\text{ppm of H}_2\text{S} = 17000 \left( \frac{a \times b - c \times d}{e} \right) = \left( \frac{a \times b - c \times d}{e} \right) \times 17000
\]  \hspace{1cm} (1)

\[
a = \text{normality of iodine} \\
b = \text{volume of iodine (ml)} \\
c = \text{normality of sodium thiosulphate} \\
d = \text{volume of sodium thiosulphate (ml)} \\
e = \text{volume of sample solution (ml)}
\]

PREPARATION OF STANDARD SOLUTIONS

0.05 N sodium thiosulphate solution

Dissolve 12.409 g sodium thiosulphate pentahydrate Na₂S₂O₃·5H₂O in 1 litre of water. Store in a dark glass bottle.

Standardisation of Iodine Solution

The iodine solution must first be standardised as described below:

1. Add 1 ml of 10% hydrochloric acid to 10 ml of a 0.1 N iodine solution.

2. Titrate with 0.05 N sodium thiosulphate until the solution is pale straw colour.

3. Add 1 ml of starch solution to produce a dark blue colour, and then titrate until this colour is just discharged.

\[
\text{Iodine normality} = \frac{(0.05) \times \text{(vol. of thiosulphate)}}{10}
\]  \hspace{1cm} (2)
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<thead>
<tr>
<th>CONTENTS</th>
<th>Page</th>
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<tr>
<td>FORM 1 - SAMPLE IDENTIFICATION AND TEST RECORD</td>
<td>E-5</td>
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<tr>
<td>FORM 2 - FULL RING TEST LOADING DATA SHEETS</td>
<td>E-6</td>
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# Form 1

**Sample Identification and Test Record**

**(Sour) Date: ...............**

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**Comments**

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Contents
FORM 2

FULL RING TEST - LOADING DATA SHEETS

JOB REFERENCE:

CLIENT:

ITEM IDENTITY:

TEST DATE: TEST AGENCY: INTERNAL STAFF/CONSULTANCY

PRINCIPAL RING DIMENSIONS BEFORE AND AFTER LOADING

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From the above data, \% SMYS is equivalent to \( \text{MPa} \)

This is the principal hoop stress \((\sigma_p)\) which is derived from the formula:

\[
\text{Principal Hoop Stress } (\sigma_p) = \frac{E}{1 - \nu^2} \left[ \varepsilon_1 + \nu \varepsilon_2 \right]
\]  

(1)

Where \(E\) is Young's Modulus, \(\nu\) is Poisson's Ratio and \(\varepsilon_1\) and \(\varepsilon_2\) are the measured strain level values at a 90° rectangular type strain gauge placed in the hoop and longitudinal axes respectively.

Hence the principal hoop strain required \((\varepsilon_1 + \nu \varepsilon_2)\) or \(\varepsilon_p\) is given using the formula:

\[
\text{Principal hoop strain } \varepsilon_p = \frac{\sigma_p}{1 - \nu^2}
\]  

(2)

which in this instance computes to a value of \(\mu \varepsilon\).

In some instances, it is required to load the ring specimen to give a nominal hoop stress based upon a stipulated internal pressure.

In such cases, the following formula may be used to compute the principal hoop stress required:

\[
\text{Principal hoop stress, } \sigma_p = \frac{p \cdot D}{2t}
\]  

(3)

where \(p\) is the quoted internal pipe pressure, \(D\) is the diameter of the ring and \(t\) is the ring wall thickness.

In meeting this loading requirement, the principal hoop stress has been computed to a value of \(\text{MPa}\). Substituting this value in Equation (2) above, the principal hoop strain computes to a value of \(\mu \varepsilon\).
**FORM 2**

FULL RING TEST - LOADING DATA SHEETS  
SHEET 3 OF 4

STRAIN GAUGE POSITIONS AND NUMBERING

- 270°  
- 0°  
- 90°  
- 180°  
- 270°

**TOP PLATE**

**BOTTOM PLATE**

<table>
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<th>GAUGE NO.</th>
<th>ANGLE FROM 0° WELD AXIS</th>
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<th>PRINCIPAL HOOP STRAIN</th>
<th>PRETENSIONING AS % OF SMYS (με)</th>
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**PROCEDURAL DEVIATIONS AGREED BY THE PRINCIPALS**

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**DATED**

**SIGNATURE**
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