HSE

Health and Safety Executive

HSE information sheet

Stress corrosion cracking of duplex stainless steel piping systems in hot chloride service

Offshore Information Sheet No 7/2007

Contents

Introduction

1. This information sheet highlights recent experience of stress corrosion cracking that has occurred to duplex stainless steel alloys in topsides process plant. These alloys are finding increasing application where high resistance to hot liquids containing chloride is required. This notice relates to topsides process plant only. It replaces Safety Notice 3/03 (SN 3/03) (issued Dec 2003) which has now been withdrawn.

Background

2. Stress corrosion cracking (SCC) of stainless steels in the presence of hot chlorides is a well-known problem. Only circumstances where this has been encountered in practice are highlighted in this notice. These are failures of duplex stainless steel piping operating at elevated temperatures in high chloride environments, caused by chloride induced SCC. In some cases cracking has led to loss of process fluid containment.
3. The failures have occurred on more than one installation. This suggests that an isolated defect or manufacturing 'fault' is not the fundamental cause. Investigations are continuing, but indicate that certain common factors are involved in the failure process. The Annex to this notice describes these factors in more detail. This information is intended to help dutyholders avoid conditions that lead to chloride-induced SCC. Specific information on chloride levels, temperatures, etc, for safe/unsafe conditions is not provided because of the uncertainties and variables that surround the issue.

Standards

4. Information presented with this notice should be considered in conjunction with engineering standards and related technical standards commonly used for process plant employing duplex stainless steels (eg NORSOK M-001 Rev. 3 Nov 2002 Materials Selection).

Actions

5. Dutyholders should identify duplex stainless steel pressure systems operating at elevated temperatures where the consequences of a loss of containment from these systems are significant, and should take action on the matters raised in this notice and Annex.

Legal requirements

6. The following legislation is relevant:

   - the Health and Safety at Work etc Act 1974, sections 2(2), 3(1) and 6;
   - the Pressure Equipment Regulations 1999 (SI 1999/2001), regulation 7;
   - the Offshore Installations (Prevention of Fire and Explosion, and Emergency Response) Regulations 1995 (SI 1995/743), regulation 9(1)(a);
   - the Provision and Use of Work Equipment Regulations1998 (SI 1998/2306), regulations 4, 5 and 6.

Further information

7. Any queries relating to this notice should be addressed to:

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This information sheet contains notes on good practice which are not compulsory but which you may find helpful in considering what you need to do

Annex

Introduction

1. Stress corrosion cracking (SCC) can cause sudden total component failure. In recent offshore instances, however, 'leak before break' occurred.
2. This note is solely about chloride induced SCC in process plant operating at temperatures above 80°C, and particularly with high pressure/high temperature (HP/HT) conditions. It is not concerned with sulphide SCC and hydrogen cracking (associated with some earlier flowline incidents[1]), or with hydrogen sulphide acting in combination with chlorides.

Observations from recent failures

3. Factors common to recent duplex stainless steel process plant failures:
    - Cracking initiated at both internal and external sites.
    - Pipework was constructed from 'standard' duplex stainless steels (Grade UNS S32205, often known as 2205, etc).
    - Point of failure was at, or adjacent to, welds with no apparent detrimental metallurgical structures.
    - No clearly defined 'metal' initiation sites (eg pits, crevices)other than proximity of welding.
    - Either water with a high concentration of chloride or a deposit/residue from such a solution was present.
    - Temperatures were typically between 120°C and 140°C.
    - Conditions were locally quiescent.
    - Leaks were detected visually by personnel.

Chlorides - internally initiated cracking

4. Some observations suggest that cracks initiated beneath deposited chlorides left by evaporated formation waters. Reduction of pressure on passing level control valves (LCVs) resulted in water evaporation, creating a chloride supersaturated liquor in the downstream flow. This led to localised deposition of chlorides. This could be exacerbated by the physical layout of the local pipework (close coupled orthogonal bends, hard Tees). Failures were highly localised. Each occurred where a pressure drop, which caused water flash with chloride concentration and salt deposition, coincided with a weld.
5. Subsequent laboratory tests reported cracking in duplex stainless steel samples at 140°C in 'oxygen free' 450g/l chloride solutions with substantial levels of $MgCl_2$.

Chlorides - externally initiated cracking

6. External cracks of pipework initiated within pipe support trunnions where seawater (eg from deluge testing) entered the support tubulars through small vent holes provided for fabrication. These holes were not sealed after installation. The internal surfaces of the supports, particularly attachment weld areas, were not protected by paint or other coating. Evaporation of the

seawater gradually concentrated the chloride solutions if the seawater was unable to drain away.

7. Cracks developed where these highly concentrated chloride solutions were in direct contact with the welds of support plates (ie high stress areas) and where temperatures were elevated. The cracks propagated through the process pipework until containment was lost.

Oxygen - external and internal cracking

8. Externally initiated cracking occurred in locations open to atmospheric oxygen. Internally initiated cracking, however, occurred in extremely low oxygen environments. The levels are estimated to be a few parts per billion or less.
9. Subsequent laboratory tests have not identified a threshold for oxygen levels below which cracking does not occur. However, the time taken to initiate cracking is extended at lower oxygen levels.

Other factors - internal failures

10. These factors appear to have been involved in internally initiated failures:
    - unexpected deposition of chloride bearing deposits on internal walls;
    - materials selection based on standard materials data and 'nominal' plant operating conditions;
    - reliance on 'nil oxygen' conditions downstream of first stage separator for protection from chloride induced SCC;
    - failures due to chloride induced SCC in operational plant despite theuse of aggressive test conditions for materials screening and selection.

Possible measures to reduce the threat from chloride induced SCC

11. In some instances there may be direct conflict between specific measures suggested here and operational requirements. For example, efforts to minimise oxygen ingress into process plant may conflict with use of wash water or chemicals. Therefore, the specific circumstances must be fully considered when deciding on the measures to be taken.

Prevention through design

Choice of duplex alloys

12. Duplex stainless steels may have greater resistance to chloride induced SCC than the austenitic alloys but they are not immune to it[2] .

High local stresses and welds

13. Stress is necessary for chloride induced SCC. All practicable measures to avoid or reduce high local stresses in plant should be considered. A common factor in recent failures was that cracking occurred at, or adjacent to, welds. Therefore, measures should be taken to minimise welding where chlorides can accumulate, for example, using external pipe supports that do not require welded attachments to hot process pipework where practicable (but beware crevices). Selection and control of welding practices and joint restraint

configurations offer significant opportunities to minimise residual stresses where welding is necessary.

Minimising oxygen

14. The absence of oxygen in hot chloride bearing streams is commonly considered to prevent chloride induced SCC occurring. However, even very low levels of oxygen appear sufficient for chloride induced SCC to occur and may be very difficult to entirely prevent in operation. Air may also be present in the operating system at start-up. Total elimination of oxygen is unlikely to be practical. Nevertheless, it is prudent to minimise entry points for air/oxygen.
15. Monitoring and minimising levels of oxygen throughout high temperature plant presents its own problems. Relying on this as a control measure is inadvisable.

Future changes of operational conditions

16. Material selection and testing should consider all reasonably foreseeable conditions of plant operations that could develop local high chloride levels. These could include:
    - operating changes within plant (pressure/temperature/throughput);
    - water cut and chemistry (eg formation waters, injection water);
    - new wells/fields/tie backs.

Avoid chloride deposits

17. Where deposition of chlorides on internal pipe walls could occur these measures can be considered during design:
    - Avoid supersaturation at any point in the process system. For example, injection of wash water can increase the amount of water present and reduce chloride concentration. Recycling process water may be preferred if this can reduce the risk of introducing oxygen without increasing other corrosion concerns.
    - Simplify the piping system to minimise unnecessary junctions and disruption to fluid flow. Consider avoiding duplicate (parallel) flow routes. This can give less tortuous flow and minimise chloride deposition by eliminating standby parallel control sets with attendant isolation valves and fittings.
    - Minimise dead legs, eg drains and normally closed bypasses. While some dead legs have lower temperatures, particularly away from the main flow path, others have heat tracing to maintain high temperature conditions.
    - Avoid close-coupled double orthogonal bends that may lead to swirling flow and chloride deposition.
    - Use large radius bends for changes in direction (ie typically 3D or greater radius) where flow patterns are likely to be significantly disturbed (eg where straight piping runs are short).
    - Avoid specifying valve types that could promote unpredictable flow patterns in susceptible locations. Axial flow control valves may have advantages in these situations. A straight run downstream of control valves of at least 5D and preferably 10D allows some flow stabilisation.

External protection

18. Coating systems are effective in preventing chlorides from contacting susceptible areas only when in good condition. Personnel should be made aware of the need to avoid surface damage and report any such damage they find. Regular inspections, maintenance and timely repair of coatings should be part of the corrosion management system.

Plant operations

19. Operational practice can reduce risks. The suggestions made here should be carefully evaluated prior to application as they may incur other difficulties or penalties:
    - Dilute high chloride wells by commingling with low chloride wells.
    - Where flashing could concentrate brine, increase the amount of water present, eg allow extra water to flow in the produced hydrocarbon stream (but beware oxygen ingress).
    - Ensure 100% availability of wash water.
    - Minimise the oxygen content of injected chemicals, eg use high-grade pure nitrogen blanket in storage (but note the problems of monitoring and maintaining low oxygen levels).
    - Purge plant with pure nitrogen following air ingress (eg after invasive maintenance).

Existing plant supports and other potential sites for external cracking

20. Recent failures occurred on the external surface of pipework within pipework support trunnions with open vent holes. For existing support trunnions, sealing vent holes may limit future ingress of brine, but conditions for initiation of chloride induced SCC may already exist. Removal of chlorides prior to sealing would be required, but may not prevent propagation of existing cracks. Other externally welded sites, such as doubler plates and reinforcement pads, should be sealed to ensure there are no crevices for chloride accumulation after first ensuring chlorides are not already present. Replacing affected pipe spools and supports may be justified in some cases.

Monitoring and inspection

21. Chloride induced SCC generally manifests itself as sudden cracking with little warning. Techniques that rely on detecting incipient cracking as a predictive tool are being used or are under evaluation. HSE cannot comment on the effectiveness of the various techniques at this time. In the meantime, preventative measures should be the primary control.

Summary and conclusions

- Inherent safety through design is the most effective means of reducing the risk of chloride induced SCC in duplex stainless steels.
- Testing and selection of materials and coatings for plant must consider the full range of reasonably foreseeable operational conditions.
- Failures of duplex stainless steels in process plant due to external chloride induced SCC occurred in conditions known to be 'unsafe'.

- These external failures reinforce the need for vigilance in protecting and monitoring external surfaces, particularly at high stress areas such as welds and where chloride concentrations can develop and within closed support trunnions.
- Designers should consider avoiding 'welded on' components for operational lines and plant where possible.

- Failures due to internally initiated chloride induced SCC were unforeseen, possibly because of assumptions about very low oxygen levels.

    - Relying on low oxygen levels as a primary protection measure against chloride induced SCC is not advisable.
    - Chloride deposition within pipework should be avoided by both design and operation.

References

1. A guideline to the successful use of duplex stainless steels for flowlines Dr L Smith et al, Duplex 2000 Conference, Houston, 29 Feb-1 Mar 2000.
2. Stress corrosion cracking resistance of duplex stainless steels OTH440/94 HSE Books 1995 ISBN 0 7176 0915 4.