Materials System Specification

01-SAMSS-016 20 March 2012

Qualification of Storage Tanks and Pressured Equipment for Resistance to Hydrogen-Induced Cracking

Document Responsibility: Materials and Corrosion Control Standards Committee

Saudi Aramco DeskTop Standards

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Previous Issue: 19 September 2011 Next Planned Update: 20 March 2017

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1 Scope

1.1 This specification is supplementary to the current NACE TM0284 - 2003 and covers the following:

- Storage Tanks under the scopes of 32-SAMSS-005, 32-SAMSS-006 and 32-SAMSS-030.
- Pressure Vessels under the scopes of 32-SAMSS-004 and 32-SAMSS-036.
- Heat Exchangers under the scopes of 32-SAMSS-007, 32-SAMSS-011, 32-SAMSS-019, 32-SAMSS-027 and 32-SAMSS-028.

1.2 Mandatory Requirements

1.2.1 This specification must be provided in full by the Buyer, Agent or other intermediary to the primary Vendor or Manufacturer at both bidding and purchasing processes. Both the steel manufacturer and vendor shall fully comply with this specification. They must provide documentation (see Appendix A) supporting their capability to manufacture and supply HIC-resistant products. For new Vendors, a current clients' list for HIC-resistant products shall also be required.

1.2.2 HIC resistant Plates intended for the manufacturing of eqipments listed in scope above shall be procured from an approved Saudi Aramco steel mill.

Commentary:

Contact Saudi Aramco buyer for a list of approved steel mills for supplying HIC resustant steel.

1.2.3 Pseudo-HIC Resistant steel shall not be used to fabricate pressure vessels intended for sour service application. Steel that passes the HIC test, but has not been initially manufactured to be HIC resistant steel shall not be used.

1.2.4 The Mill Test certificate shall state that the radiation level from the steel plates is less than 100 beckerels/gram.

2 Conflicts and Deviations

2.1 Any conflicts between this specification and other applicable Saudi Aramco Materials System Specifications (SAMSSs), Engineering Standards (SAESs), Standard Drawings (SASDs), or industry standards, codes, and forms shall be

resolved in writing by the Company or Buyer Representative through the Manager, Consulting Services Department of Saudi Aramco, Dhahran.

2.2 Direct all requests to deviate from this specification in writing to the Company or Buyer Representative, who shall follow internal company procedure SAEP-302 and forward such requests to the Manager, Consulting Services Department of Saudi Aramco, Dhahran.

2.3 Conflicting Requirements and Deviations

In case of conflict or deviation between this specification and drawings, design, data sheet or order not specifically covered as an exception by the Purchase Order, the Buyer shall be consulted and a ruling in writing obtained by the Vendor before any work is done.

3 References

The following references in force on the date of the Purchase Order form a supplementary part of this specification, as applicable.

3.1 Saudi Aramco References

Saudi Aramco Engineering Procedures

SAEP-302	*Instructions for Obtaining a Waiver of a Mandatory Saudi Aramco Engineering Requirement*

Saudi Aramco Materials System Specifications

32-SAMSS-004	*Manufacture of Pressure Vessels*
32-SAMSS-005	*Manufacture of Atmospheric Tanks*
32-SAMSS-006	*Manufacture of Low Pressure Tanks*
32-SAMSS-007	*Manufacture of Shell and Tube Heat Exchangers*
32-SAMSS-011	*Manufacture of Air-Cooled Heat Exchangers*
32-SAMSS-019	*Manufacture of Plate and Frame Heat Exchangers*
32-SAMSS-027	*Manufacture of Electric Heat Exchangers*
32-SAMSS-028	*Manufacture of Double Pipe Heat Exchangers*
32-SAMSS-030	*Manufacture of Small Tanks*
32-SAMSS-036	*Manufacture of Small Pressure Vessels*

Saudi Aramco Inspection Requirements

Form 175-010200 *Inspection and Testing Requirements - HIC Testing*

3.2 Industry Codes and Standards

American Society for Testing and Materials

ASTM A435 *Standard Specification for Straight-Beam Ultrasonic Examination of Steel Plates*

ASTM A578 *Standard Specification for Straight-Beam Ultrasonic Examination of Plain and Clad Steel Plates for Special Applications*

National Association of Corrosion Engineers

NACE TM0284 - 2003 *Evaluation of Pipeline and Pressure Vessel Steels for Resistance to Hydrogen-Induced Cracking*

4 Definitions

For the purpose of this specification, the following definitions shall apply:

Agent: The Company representing the Vendor.

Buyer: Saudi Aramco Purchasing Department Representative.

Buyer's Representative: The Saudi Aramco person(s) designated by the Purchasing Department to monitor/enforce the contract.

Manufacturer: Company which manufactures the required steel plates.

Pseudo-HIC Resistant Steel: Plate that is not fabricated utilizing the quality control/assurance and fabrication measures to intentionally produce HIC resistant steel.

Responsible Standardization Agent (RSA): The Responsible Standardization Agent for commodity assigned by Engineering Services/CSD, the responsible agency, with the concurrence of materials standardization, to be the technical authority on issues related to commodity.

Third Party Laboratory: An independent testing laboratory not affiliated with the vendor or manufacturer.

Vendor: Vessel manufacturer.

5 Test Solution Requirements

Solution A of the current NACE TM0284 - 2003 shall be used for qualifying the products listed above in Section 1.1. The test procedure is detailed in Appendix B.

6 Quality Control Requirements

The Chairman of the Materials and Corrosion Control Standards Committee shall approve HIC Test Laboratories.

For quality control, the following minimum requirements shall be met:

6.1 Verify the Inspection and Testing Requirements specified in Form 175-010200 HIC Testing are completely satisfied. This task shall be carried out by Saudi Aramco Inspection Representative, e.g., Vendor Inspection Division.

6.2 HIC control samples, provided by the Manufacturer/Vendor, shall be used for all tests. These control samples shall have demonstrated HIC-cracking sensitivity, i.e., Average Crack Length Ratio (CLR) exceeding 20% in Solution A.

6.3 The purity of the H_2S gas shall be 99.5% minimum. H_2S gas generated from chemical reactions, e.g., Kipps apparatus, is not acceptable as a source of H_2S gas.

6.4 H_2S concentration shall be measured by iodometric titration as per the current NACE TM0284 - 2003, i.e., $\geq$ 2,300 ppm. Measurements shall be conducted at start of test, i.e., after 1 hour (saturation) and at the end of test (96 hours).

6.5 The HIC testing laboratory shall provide documentation supporting the adequate training of technicians or engineers undertaking the evaluation of CLR and CTR measurements.

6.6 Should the Vendor's HIC test results be rejected by Saudi Aramco, re-testing may be referred to an independent 3rd party laboratory acceptable to Saudi Aramco for resolution. This laboratory shall use HIC test methods and control samples in accordance with this specification.

7 Acceptance Criteria

The criteria presented below include HIC Testing Sensitivity and Non-Destructive Inspection.

7.1 HIC Sensitivity Testing

The following sections cover HIC sensitivity testing for raw material intended for fabrication of storage tanks and pressured equipment. The HIC test shall be performed in accordance with Appendix B of this specification.

7.1.1 Raw Material (Plate)

Testing shall be performed by the Manufacturer/Vendor or 3rd party laboratory acceptable to Saudi Aramco.

- Testing shall be carried out on all heats.
- Three samples shall be cut from one end, across the width of the plate. These samples shall be oriented longitudinally, i.e., along the principal rolling direction (Figure 1). The long axis of the coupons shall be parallel to the rolling direction of the plate. If the steel is produced by the ingot casting method, the samples shall be taken from the end of the plate representing only the top of the ingot.
- If several thicknesses are produced from a plate of a single heat, then the thinnest shall be tested.

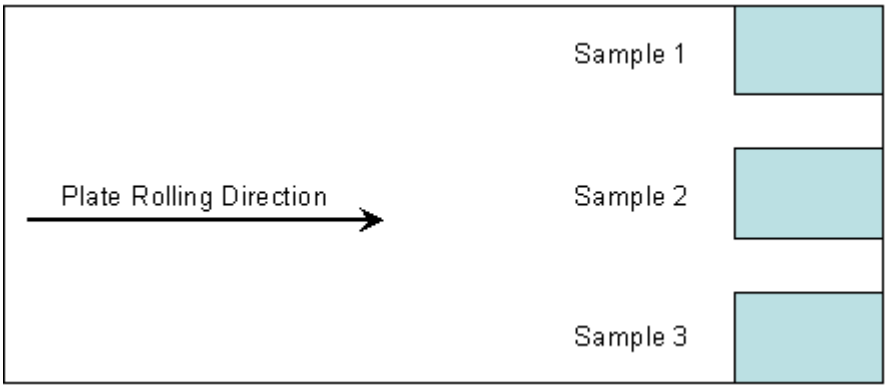


Figure 1 – Plate Sampling Location Diagram

7.1.2 The Plate shall be HIC tested as follows:

- One plate from each heat supplied on the Purchase Order shall be tested.
- If more than one thickness of plate is produced from a single heat, the thinnest plate shall be tested.

7.1.3 Specimens intended for HIC testing shall be in the same heat treatment condition of the plates. Conducting stress relieving on the HIC specimens is not acceptable if the delivered plates have not been stress relieved at a minimum temperature of 593°C for 1 hour/1 inch.

7.1.4 Stress relieving of the HIC specimens at a minimum temperature of 593°C for 1 hour/1 inch is deemed acceptable if declaration from the

vessel manufacturer is obtained confirming the application of PWHT on the vessel subsequent to fabrication.

7.1.5 HIC Testing Acceptance Criteria

HIC is evaluated in terms of crack length ratio (CLR) and crack thickness ratio (CTR) as given below. These values shall be reported for each metallographic cross-section examined and as the calculated average of three sections per specimen. The results for each specimen, i.e., the average of the three sections examined, shall be used for evaluating HIC sensitivity.

Definitions:

The "Crack Length Ratio"(CLR) is defined as the sum of the lengths of the individual longitudinal cracks divided by the width of the polished specimen face times 100% (Figure 2).

The "Crack Thickness Ratio" (CTR) is defined as the sum of the thickness of crack arrays divided by the thickness of the polished specimen face times 100% (Figure 2).

a) Acceptable

Surface Blistering - Cracks associated with surface blistering which at no point extend more than 1 mm from the specimen surfaces are acceptable. Cracks extending deeper than 1 mm shall be evaluated as per Appendix B Section 7C of this specification.

Longitudinal cracking is acceptable as long as the calculated average CLR for each individual specimen is less than or equal to 10%.

Transverse or stepwise cracking is acceptable providing the calculated average CTR for each individual specimen is less than or equal to 3%.

b) Not Acceptable

Longitudinal cracking in which the calculated average CLR of any of the specimens exceeds 10% is not acceptable.

Transverse or stepwise cracking in which the calculated average CTR of any of the specimens exceeds 3%.

7.1.6 Retesting Requirements

A heat that fails the acceptance criteria above may be retested as follows:

a) The plate that failed the test shall be rejected. However, two additional pieces of plate may be selected at random from the same heat for further testing. If both of the retest groups pass, all plates in the heat are acceptable except the one from which the initial test coupons were taken.

b) If one or both of the retest groups fail to meet the acceptance criteria, the heat shall be rejected and materials specified in the Purchase Order shall either be tested heat by heat or rejected entirely at the discretion of the Vendor.

7.1.7 Additional testing shall be required if the steel-making procedure is significantly altered during production.

Revision Summary

20 March 2012 Revised the "Next Planned Update." Reaffirmed the content of the document, and reissued with no other changes.

Appendix A – Documentation Required for Bid Evaluation

This Appendix shall be highlighted and included in the purchase requisition (PR) intended for first order of the new vendor.

The bid package shall include the following items:

A.1 Documentation detailing that the proposed steel manufacturing process and controls will result in a product resistant to hydrogen induced cracking. Specific measures that will be taken to ensure HIC resistance will be stated.

A.2 Proposed chemical composition and range based on check analysis including Al, B, C, Ca, Cr, Cu, Mn, Mo, Ni, Nb, N, P, Si, S, Ti and V.

A.3 Documentation for HIC testing facility, including, but not limited to the following:

- Description of the HIC testing setup/apparatus (schematic required) to be used for qualifying the plates.
- Purity of the utilized salts and H_2S for the test solution.
- Detailed procedure describing the testing, metallographic preparation and evaluation of HIC specimens.
- Documentation confirming availability (with Manufacturer/Vendor) of HIC Control Samples with demonstrated HIC-sensitivity, i.e., **average CLR exceeding 20% in Solution A**.
- The Manufacturer/Vendor shall qualify his test method using HIC control samples.
- If the Manufacturer/Vendor does not have a HIC testing facility acceptable to Saudi Aramco or its representative, then he must provide documentation supporting that testing shall be conducted by an independent 3rd Party Laboratory meeting Saudi Aramco's approval.

A.4 Description of NDT equipment that will be used during plate inspection.

A.5 A current clients list for HIC-resistant products.

Appendix B – Test Procedure for Evaluating HIC in H_2S Saturated Solution A

For the purpose of this specification, the test method used for determining the HIC susceptibility of steels shall be Solution A, as described in NACE TM0284 - 2003, except as modified in this Appendix. The testing shall be performed using the apparatus given in Figure 3 of this specification, using glass vessels or other inert materials. All test batches shall include a control sample with demonstrated HIC-sensitivity, i.e., average CLR exceeding 20%. Additions, deletions, or modifications to NACE TM0284 - 2003 are given below. The sections referenced below are as those given in NACE TM0284 - 2003.

Section 1 - General

Modify (B.1.2) The test method consists of exposing unstressed test specimens to a standard test solution – Solution A, sodium chloride (NaCl), acetic acid (CH_3COOH) solution saturated with H_2S at ambient temperature and pressure.

Modify (Paragraph 1.4) Acceptance criteria are as given in paragraph 7.1.4 of this specification.

Section 2 - Reagents

Modify (B.2.1) The reagents for Solution A shall be nitrogen gas for purging, H_2S gas, NaCl, CH_3COOH and distilled or deionized water. The used nitrogen shall be minimum industrial grade, 99.5% pure.

Caution: *H_2S is extremely toxic and must be handled with extreme care (see Appendix A of NACE TM0284 - 2003).*

Modify (B.2.3) The gases shall be reagent grade or chemically pure. The purity of the H_2S gas shall be certified to be 99.5% minimum. H_2S gas generated from chemical reactions, e.g., Kipps apparatus, is not acceptable as a source of H_2S gas.

Delete Paragraph 2.4

Section 5 - Test Specimens –Plate

Add (B.5.2.1) Only one set of three specimens is required.

Section 7 - Evaluation of Test Specimens

Modify (Paragraph 7.3) Substitute Figure 11 with Figure 2 of this Specification

Add Paragraph 7.3

For each section containing cracks, a photograph shall be taken of the complete cross-section at a magnification no less than 5X. Higher magnifications shall be used as necessary to resolve fine cracks.

The defects listed below shall be disregarded.

a) Features such as inclusions that cannot be definitely identified as cracks.

b) Isolated, definitely identifiable cracks shorter than 0.1 mm in length.

c) Blisters and their associated cracking which at no point extend more than 1mm from the inner and outer surfaces of the test specimen. If any part extends more than 1 mm from the surfaces, the entire blister/crack system shall be counted.

d) Isolated longitudinal cracks (i.e., cracks having a thickness less than or equal to 0.1 mm) having no part more than 1.0 mm from the inner and outer surfaces of the test specimen. If the cracks are located partly within 1.0 mm from the surface and partly deeper than 1.0 mm into the specimen, the entire crack shall be counted.

Modify (Paragraph 7.4) Delete all references to Crack Sensitivity Ratio (CSR)

Section 8 - Reporting of Test Results

The CLR results of the control sample shall be reported.

Delete All paragraphs in Section 8. Replace with the requirements given below.

Add Data to be provided

(B.8.1) Location and dimensions of coupons.

(B.8.2) pH of H_2S saturated solution at the start and end of the test.

(B.8.3) Chemical composition of material tested, including Al, B, C, Ca, Cr, Cu, Mn, Mo, Ni, Nb, N, P, Si, S, Ti and V.

(B.8.4) Results of cracking evaluation.

(B.8.5) Photomicrographs of metallographically-polished (1 micron finish) specimens of typical parent material microstructures on a plane with the same orientation as that used for cracking evaluation:

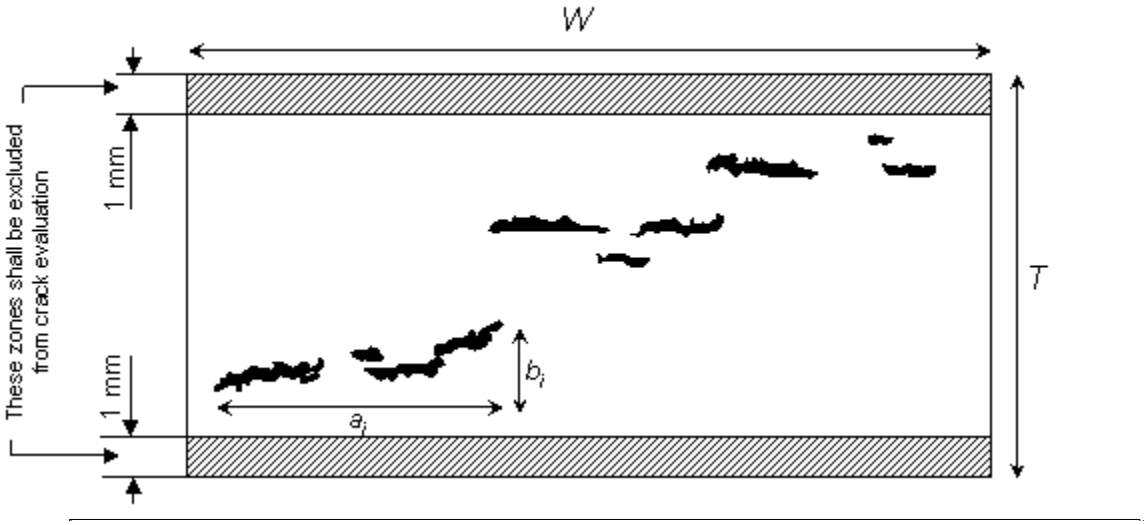
i) (Unetched) The types of inclusions in the steel

ii) (Etched) Parent material microstructure

The magnification shall be sufficient to clearly show the details being photographed. Normally a range of 100X to 500X shall be used.

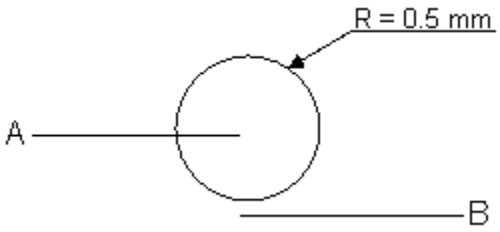
(B.8.6) The Vickers Hardness method shall be performed using a maximum test load of 5 or 10 kg. Measurements shall be carried out on metallographically-polished (1 micron finish) specimens and the average hardness shall not exceed 250 HV.

(B.8.7) Cracks are evaluated according to crack length ratio (CLR) and crack thickness ratio (CTR) by measuring the total crack length and extend of stepwise cracking respectively.

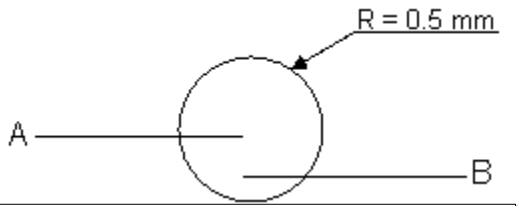


Length of stepwise crack: $\sum a_i$ Thickness of stepwise crack: $\sum b_i$

$$CLR = \frac{\sum_{i=1}^{n} a_i}{W} \times (100\%) \qquad CTR = \frac{\sum_{i=1}^{n} b_i}{T} \times (100\%)$$

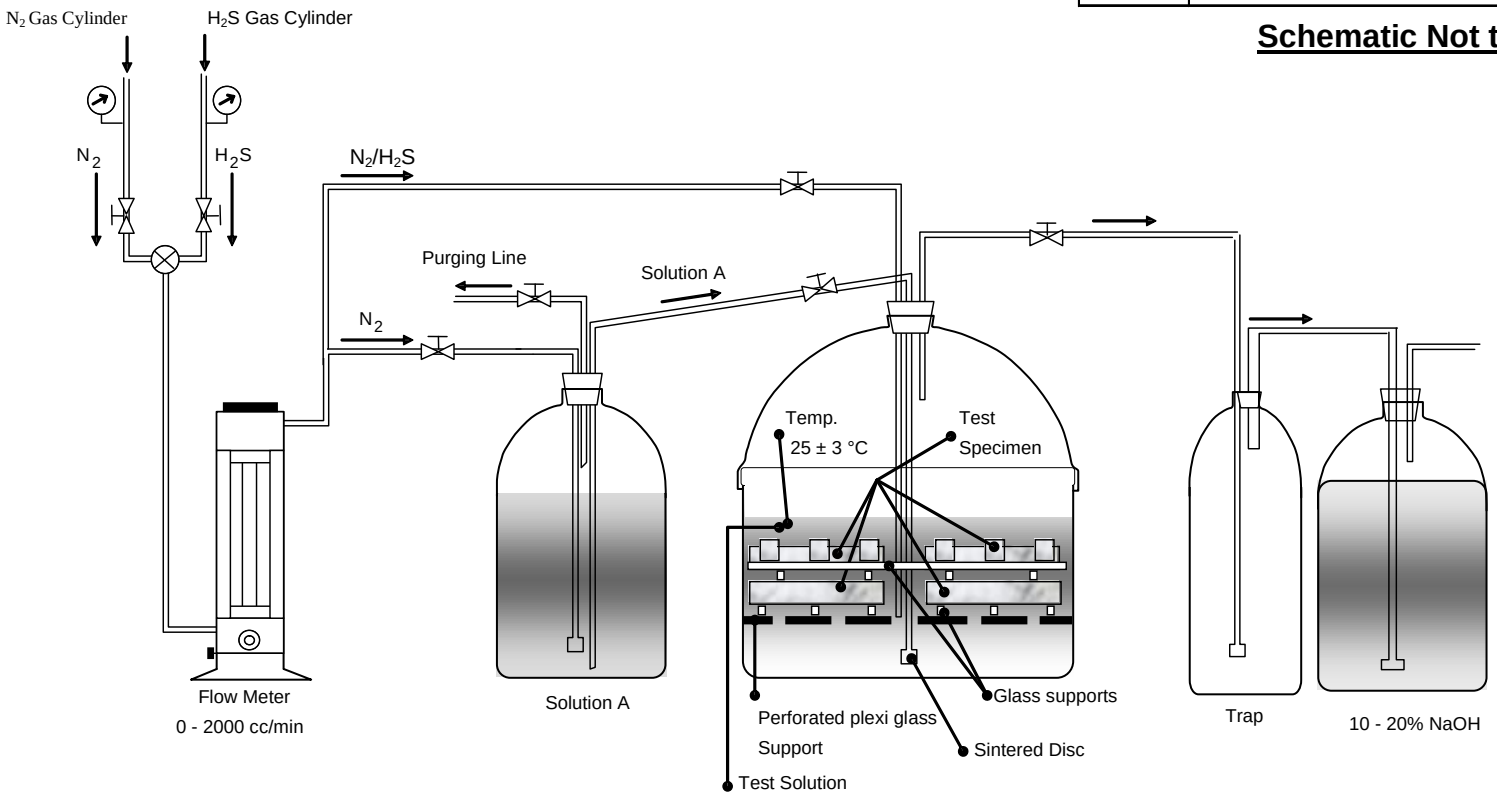


A and B considered as two separate cracks



A and B considered as a single crack

Figure 2 – Method for Measuring and Evaluating Cracks



Note: *The test vessel should be placed in a temperature-controlled bath at 25 ±3°C*

Figure 3 – HIC Testing Apparatus