



# Materials System Specification

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01-SAMSS-333

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High Frequency Welded Line Pipe

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Document Responsibility: Materials and Corrosion Control Standards Committee

## Saudi Aramco DeskTop Standards

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## I Scope

This Specification only applies to high frequency welded (HFW) pipe, outside diameter 114.3 mm (NPS 4) and larger, for use in Saudi Aramco Requirement Class B and Class C. Pipes manufactured to this specification must be in accordance with International Standard [API SPEC 5L/ISO 3183](#) to product specification level 2 (PSL 2).

### *Commentary Note:*

*Class C service consists of offshore, sour gas or corrosion service, as defined by Saudi Aramco Engineering Standard [SAES-L-133](#). Class B service consists of all services other than Class C services. Requirements for Class B and Class C services are defined by [SAES-L-136](#).*

Unless stated to the contrary in the purchase requisition and the purchase order, pipe manufactured to this specification must be suitable for external coating with fusion bonded epoxy at a later date by the Purchaser. If the pipe will be internally coated, it shall be so stated in the purchase requisition and the purchase order.

## II Conflicts and Deviations

- 1) Any conflicts between this Specification and other applicable Saudi Aramco Materials System Specifications (SAMSSs), Engineering Procedures (SAEPs), 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) 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.

## III Normative References

The manufacture and purchase of material covered by this specification shall comply with the latest edition (as per the PO date) of the references listed below, as noted.

### A. Saudi Aramco References

Saudi Aramco Engineering Procedure

[SAEP-302](#)

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

## Saudi Aramco Engineering Standards

<a href="#"><u>SAES-L-131</u></a>	<i>Fracture Control of Line Pipe</i>
<a href="#"><u>SAES-L-133</u></a>	<i>Corrosion Protection Requirements for Pipelines, Piping and Process Equipment</i>
<a href="#"><u>SAES-L-136</u></a>	<i>Pipe Selection and Restrictions</i>

## Saudi Aramco Materials System Specifications

## Saudi Aramco Inspection Requirements

Form <a href="#"><u>175-010300</u></a>	<i>Pipe: Plain End Electric Resistance or Electric Induction Welded Steel Pipe</i>
Form <a href="#"><u>175-010210</u></a>	<i>HIC Testing: ANSI/<a href="#"><u>API SPEC 5L</u></a> Pipe</i>

## B. Industry Codes and Standards

## American Petroleum Institute

[API SPEC 5L](#) 45<sup>th</sup> Ed. *Specification for Line Pipe*

## American Society for Testing and Materials

<a href="#"><u>ASTM D1141</u></a>	<i>Standard Practice for the Preparation of Substitute Ocean Water</i>
<a href="#"><u>ASTM E112</u></a>	<i>Estimating the Average Grain Size of Metals</i>
<a href="#"><u>ASTM E381</u></a>	<i>Standard Method of Macrotech Testing Steel Bars, Billets, Blooms, and Forgings</i>

## American Society for Non Destructive Testing

<a href="#"><u>ASNT SNT-TC-1A</u></a>	<i>Recommended Practice for Personnel Qualification and Certification</i>
<a href="#"><u>ASNT CP-189</u></a>	<i>Standard for Qualification and Certification of Nondestructive Testing Personnel</i>

## International Organization for Standardization

<a href="#"><u>ISO 404</u></a>	<i>Steel and Steel Products - General Technical Delivery Requirements</i>
<a href="#"><u>ISO 7438</u></a>	<i>Metallic Materials - Bend Test</i>
<a href="#"><u>ISO 7870-2</u></a>	<i>Control Charts - Part 2 Shewhart Control Charts</i>
<a href="#"><u>ISO 10893-10</u></a>	<i>Seamless and Welded (Except Submerged Arc-Welded) Steel Tubes for Pressure Purposes - Full</i>

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*Peripheral Ultrasonic Testing for the Detection of Longitudinal Imperfections*

[ISO 10893-11](#)

*Electric Resistance and Induction Welded Steel Tubes for Pressure Purposes - Ultrasonic Testing of the Weld Seam for the Detection of Longitudinal Imperfections*

[ISO 10474](#)

*Steel and Steel Products - Inspection Documents*

[ISO 11496](#)

*Seamless and Welded Steel Tubes for Pressure Purposes - Ultrasonic Testing of Tube Ends for the Detection of Laminar Imperfections*

European Standard

[EN 473](#)

*Non-Destructive Testing - Qualification and Certification of NDT Personnel - General Principles*

#### IV Modifications to [API SPEC 5L](#)

The following paragraph numbers refer to [API SPEC 5L/ISO 3183](#), which is the basis of this specification. The text in each paragraph below is an addition or modification to [API SPEC 5L/ISO 3183](#), as noted. Paragraph numbers not appearing in [API SPEC 5L/ISO 3183](#) are new paragraphs to be inserted in numerical order.

##### 1 **Scope [modification]**

All pipes shall be manufactured to PSL 2, with the additional requirements contained in this specification.

##### 2 **Conformity**

##### 2.3 Compliance to this international standard [modification]

The quality system shall be subject to approval by Saudi Aramco Inspection Department/Vendor Inspection Division when the manufacturer is surveyed for consideration as a qualified supplier and the quality system shall be assessed periodically thereafter.

##### 4 **Terms and Definitions**

##### 4.23 HFW Pipe [modification]

EW pipe produced with a welding current frequency equal to or greater than 150 kHz

4.62 Test Unit [addition]

A test unit shall not exceed 100 pipes.

4.68 Pseudo-HIC Resistant Steel [addition]

Coil that is not manufactured utilizing the quality control/assurance and fabrication measure to intentionally produce HIC resistant steel.

4.69 Class IV Service [addition]

This class is for gas, two-phase flow, and liquid lines such as NGL, whose vapor pressure exceeds 690 kPa (100 psia).

4.70 Continuous Electronic Process Control (CEPC)

CEPC shall be capable of continuous monitoring and recording of heat input variables (line speed, voltage and current or welding power) and seam heat treatment variables (heat treatment temperature and line speed) with alarm and automatic pipe marking for upset conditions outside of the qualified process limits (See [Annex B.6, Figure 11](#)). In addition, it is highly desirable to extend CEPC to monitor squeeze roll force or another variable directly related to metal distortion angle (see [Figure 10](#)).

Squeeze roll force or another variable directly related to variations in distortion angle shall be monitored and recorded and used for feedback control for all Class C services.

## 7 Information to be supplied by the Purchaser

7.2 c) Additional Information [modification]

Indicate in the Purchase Order only when required:

1. Intended class of service (Class B or Class C services)
  2. Suitable for internal coating (see Scope, 9.10.7, 9.11.3.3 c)
  3. Suitable for automatic welding (See 9.11.3.6)
  4. Suitable for sour service (paragraph 8.3.7, Annex H and K shall apply)
  5. Non-sour service (See 11.1.5)
  6. If the line pipe is meant for Class IV service ([Annex G](#) shall apply), it shall be so specified (see G.1.3 for definition of Class IV service) and the impact energy values shall be stated.
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## **8 Manufacturing**

### **8.1 Process of Manufacture**

This specification applies to HFW pipe only. [modification]

- 8.1.1 A manufacturer, not previously qualified to bid on this specification, shall submit at least one complete Manufacturing Procedure (see [Annex B](#)) for approval. After review of manufacturing procedure, the mill shall be audited.

For approval for Class C Services, candidate manufacturer shall submit documentation, including quality control and process control records, of successful production on a total of 200,000 feet of pipe manufactured to this specification for Class B services, or equivalent production for other major oil companies of high quality pipe for severe wet, sour service. At least two different pipe diameters shall be represented in the production records.

Once approved, a manufacturer may qualify additional procedures after award of the Purchase Order(s), as described below.

A specific manufacturing procedure shall be qualified for the job (see [Annex B](#)). A procedure must be qualified and approved for each set of essential variables (see B.0 and B.3.).

Minor exceptions to this specification may be addressed in the Manufacturing Procedure approval process ([Annex B](#)). In these cases, formal waivers are not required, but intended exceptions and Saudi Aramco approval must be in writing.

Major deviations from this specification shall be submitted 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.

At the conclusion of production, the manufacturer shall submit a Postproduction Process Control Report to the Saudi Aramco Consulting Services Department (CSD) / Capital Program Support Division (CPSD). This report shall be in electronic spreadsheet format (email submittal is acceptable). The report shall include a summary of pipe quality control tests and details relevant to any rejects. The report shall also include all of the results for tests required in 10.2.3.3, 10.2.4.6, 10.2.4.7 and 10.2.5. For Class C services, each metal distortion angle measurement, the associated metal flow factor (distortion angle ÷ girth reduction at squeeze roll per Annex B.6.2.b) and heat input factor shall be reported.

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- 8.3.10 For all pipe produced to this specification, the strip edges shall be milled or machined before welding. Automatic seam tracking/position control shall be used for the heat treatment and NDT stages. [addition]

Process Control, Option 1

Verifiable control of process variables is required for all pipe produced. The welding process shall also be qualified prior to production, in accordance with this specification. Basic process control requirements for welding are:

1. Qualify the process limits in accordance with [Annex B.6](#).
2. During production, verify maintenance of acceptable welding conditions and adequate process control. Either of two methods is acceptable for use:

- a. Continuous Electronic Process Control (CEPC) (see 4.70).

For every pipe length, heat input variables (voltage, current and line speed or heat input) and seam heat treatment variables (heat treatment temperature and line speed) shall be continuously monitored and shown to be within the qualified process limits (See [Figure 11](#)) by electronic data acquisition. Metal distortion angle shall be verified metallographically in accordance with 10.2.5.5. If squeeze roll force or another parameter proven to have direct correlation with flow angle is measured as part of CEPC, then the metal distortion angle shall be measured metallographically at least once per shift. CEPC methods shall not require Statistical Sampling and Statistical Process Control (SPC) methods for control of voltage, current, line speed, and metal distortion angle. CEPC shall immediately identify and segregate individual pipe lengths whose qualified process limits ([Annex B.6](#)) have been exceeded.

- b. Combination of CEPC and SPC (this option is not acceptable for Class C services)

If CEPC is used to control heat input process variables, but not metal distortion angle, SPC can be used to control metal distortion angle in accordance with the frequency described in 10.2.5.5. The average of the tests required for each test unit shall represent one sub-group to be charted by SPC in accordance with [ISO 7870-2](#) using control limits as specified in Annex B.6.5.

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3. Qualification of welding conditions shall verify that the primary power line voltage to the mill, and within the mill, does not fluctuate significantly. The mill must demonstrate and assure maintenance of adequate weld power control.

#### Process Control, Option 2

Verifiable control of process variables is required for all pipe produced. A manufacturer may submit its own proprietary process control procedures for review. The information shall be treated as confidential by Saudi Aramco. The proprietary process control system must meet the intent of this specification to define relevant process variables, relate these variables to production of acceptable pipe, and maintain process control during production. Deviations from Option 1 requirements (above) must be very well supported with detailed procedure descriptions, a large amount of production data, and appropriate statistical analysis.

- 8.3.11 HIC resistant coils intended for the manufacturing of pipes shall be procured from an approved Saudi Aramco steel mill. [addition]

#### *Commentary:*

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

- 8.8 Treatment of Weld Seams in EW and LW Pipes

- 8.8.2 LW pipe and PSL 2 HFW pipe [modification]

The full width and thickness of the weld seam shall be heat treated after welding so that the weld microstructure and hardness requirements in paragraph 10.2.5 are met. Full body normalizing is optional. CEPC, PSL 2, when employed shall be used to assure the ID heat treat width and centering by monitoring heat treatment temperature and line speed as related to temperature control. Failure or abnormal operation of the seam heat treatment equipment shall trigger an alarm and automatic pipe marking. Failure to control the ID heat treat width, and centering, by SPC shall cause the test unit in question to be rejected.

## **9 Acceptance Criteria**

- 9.2 Chemical Composition [modification]

- 9.2.2 Heat and Product Analysis
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**Table 1**

Element	Maximum % (Class B)	Maximum % (Class C)
Carbon	-	0.08
Silicon	0.35	0.30
Manganese	1.4 (Table 5/H.1 note b applies)	1.40 (Table 5/H.1 note b applies)
Sulfur (non-sour service)	0.006	0.003
Nb+V+Ti	-	0.12 (modifies note d/g/e of Table 5/H.1 )

**Note:** Chemistry requirement of Table H.1 applies for all sour service (Class B and C) with above restrictions.

**Table 2**

Wall thickness, mm	Maximum $CE_{I\!W}$	Maximum P <sub>cm</sub>
< 11.1	0.42	0.24
11.1 – 12.6	0.41	0.22
12.7 – 15.8	0.40	0.22
> 15.8	0.39	0.21

## 9.6 Flattening Test [modification]

In the first step of the flattening test, no weld opening shall occur when the pipe is flattened as follows, and continue flattening to report the height when a weld opening does occur or until opposite walls of the pipe meet:

Class B		Class C	
D/t	H/D	D/t	H/D
>50	0.4	>48	0.3
30-50	0.5	35-48	0.4
<30	0.6	<35	0.5

where: D = specified outside diameter

t = specified wall thickness

H = distance between flattening plates

All values in the same unit. If the flattening height required by [API SPEC 5L](#) / [ISO 3183](#) for a certain diameter and wall thickness is more stringent than the

above requirement, the requirement of [API SPEC 5L/ISO 3183](#) shall be followed.

9.8 CVN Impact Test for PSL 2 Pipe [modification]

9.8.1 For Class C services, for the weld area impact tests required to qualify the Manufacturing Procedure (B.5) and the Process Limits (B.6), sets of six specimens shall be tested instead of the usual sets of three specimens. For the impact tests during pipe production, sets of three specimens shall be used. In all cases, the average absorbed energy shall not be less than the value specified in the purchase order for the pipe body. The lowest individual reading shall not be lower than 75% of the specified value and shall not be lower than 40 J.

9.8.3 The energy values for class IV service shall be as specified in the purchase order. For all other services, the impact testing of the weld shall be as stated in this paragraph of [API SPEC 5L](#).

9.9 DWT test for PSL 2 welded pipe [modification]

DWT test results shall be reported in accordance with [API RP 5L3](#).

9.10.7 Other Surface imperfections [addition]

d) Pipe that is to be externally and/or internally coated shall be free of scabs, slivers, laps, seams, and other conditions that would impair coating, including, but not limited to, oil, grease, tape, lacquer, and varnish.

9.11 Dimensions, Mass and Tolerances [modification]

9.11.3.3 The tolerances for Length shall be as follows:

Random length in the range 10 to 14 m shall be delivered except as specified below or otherwise specified in the Purchase Order.

- a) No pipe lengths less than 10.0 m will be accepted.
- b) Pipe lengths less than 11.6 m cannot exceed 2% of the total line item quantity.
- c) If the pipe is identified in the Purchase Order as being intended for subsequent internal coating, the maximum length of any individual pipe is 12.8 m.

9.11.3.5 Pipe that is to be joined using pipeline field automatic welding systems [addition]

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- a) The difference in outside diameter, at the ends, between any two lengths of the same Line Item shall not exceed 1.6 mm for 75% of the pipes produced.
- b) Out-of-Roundness at the ends shall not exceed  $\pm 0.5\%$  of the specified (nominal) O.D. For pipe with  $D/t < 75$ , the difference between maximum diameter and minimum diameter shall not exceed 6 mm.

## 10 Inspection

### 10.1 Types of Inspection and Inspection Documents

10.1.3.1 Saudi Aramco Inspection Requirements Form [175-010300](#) specifies the inspection and testing requirements. The certificates/data to be provided are of the [ISO 10474](#) Type 3.1.B and shall be reported in the English language. [modification]

### 10.2 Specific Inspection [modification]

#### 10.2.1 Inspection Frequency

Semi-guided root bend test shall be done for Class C service.

10.2.1.2 DWT test is required only for Class IV service for all grades of line pipe, having diameters 20 inches and larger (Table 18).

#### 10.2.3 Samples and Test Pieces for Mechanical Tests [modification]

##### 10.2.3.1 General

Three root bend tests per 10.2.4.6 shall be performed. One specimen each from the start, middle and end of each coil shall be taken. Bend test is required only for Class C services.

##### 10.2.3.3 Test Pieces for the CVN Impact Test [modification]

Full size specimens (10 mm x 10 mm) shall be used whenever possible and the pipe sample may be flattened before machining to obtain as close as possible to a full size specimen. Subsize specimens shall only be allowed when the pipe wall thickness is insufficient to provide full size specimens. In these cases the largest possible subsize specimens, obtainable by flattening or use of tapered ends, shall be used.

The axis of the notch shall be within  $\pm 0.25$  mm from the weld line. Each test piece shall be etched prior to notching in order to ensure proper placement of the notch.

Consult Chairman or Vice Chairman of the Saudi Aramco Materials and Corrosion Control Standards Committee for sizes not covered by Table 22.

#### 10.2.3.4 Test Pieces for the DWT Test

The type of notch for DWT test shall be as follows:

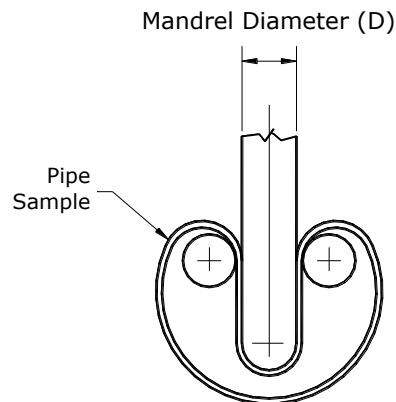
- (a) For pipe order with specified minimum average CVN value less than or equal to 70 ft-lb, the pressed type notch shall be used for the DWT test.
- (b) For pipe order with specified minimum average CVN value greater than 70 ft-lb, the Chevron type notch shall be used.

#### 10.2.3.7 Test pieces for the Flattening test

The length of each test piece shall be greater than or equal to 100 mm.

#### 10.2.4.6 Guided-bend Test [modification]

The guided-bend test shall be carried out in accordance with ISO 7438 for the Class C HFW pipe. The test may be performed on a full ring of pipe as shown below in Figure 9 - d). The full wall thickness is to be tested and no machining of the O.D. or I.D. face shall be done. Fractures or cracks caused by weld defects shall be cause for rejection of the representative coil and shall not be discarded and retested.



**Figure 9 - d) Full Ring Type**

#### 10.2.4.7 Flattening Test [modification]

Besides the two test pieces taken from both end-of-coil locations, one test piece shall also be taken from two random, but not identical, locations through the remaining length of the coil and tested with the weld at the 3 o'clock position.

*Commentary Note:*

*One coil may produce 12-34 pipe lengths depending on size and thickness.  
The intent is to get 4 tests evenly spaced throughout the coil length.  
Ideally, 4 separate pipes in the coil length are to be sampled.*

10.2.5 Macrographic and metallographic examinations

10.2.5.5 Weld microstructure and hardness tests [addition]

Frequency: One test per 100 lengths (50 lengths for Class C services).  
If, CEPC is not in place for metal distortion angle control, there shall be four lengths tested per 100 lengths produced. At least one pipe from each cast (heat) shall be tested.

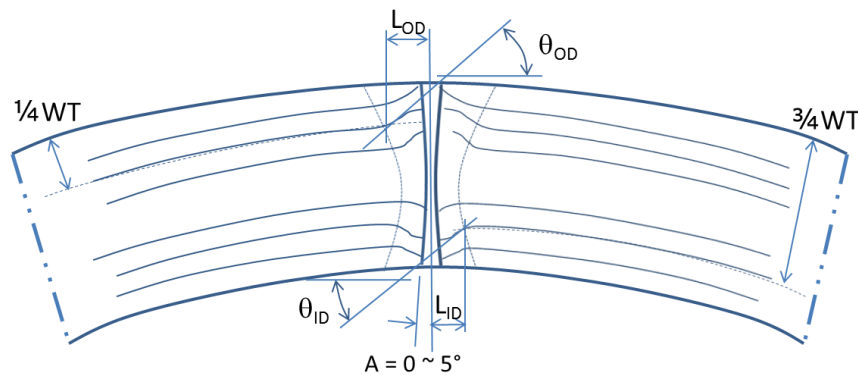
In addition, for Class C services, item f), the metal distortion angles, shall be measured metallographically at least three times per shift and correlated with the distortion angle parameter (i.e., squeeze roll load) that is being monitored and recorded as part of the CEPC.

Preparation: For each pipe tested, at least one transverse specimen of the weld area shall be polished to metallographic quality and shall be etched to provide grain boundary contrast.

Acceptance criteria: Using a metallurgical microscope or metallograph, the transverse specimen shall be examined at a magnification sufficient to easily measure grain size per [ASTM E112](#).

- a) The normalized zone shall extend through the wall and completely overlap the original weld line.
  - b) The weld seam microstructure shall contain no untempered martensite and no inclusions at the fusion line.
  - c) The grain sizes of the weld seam area and the parent metal shall be determined per [ASTM E112](#). Weld seam grain size shall not exceed parent metal grain size by more than two ASTM grain-size units.
  - d) A balanced uniform forged structure shall be present as depicted in Figure 10a and Figure 10b.
  - e) Fusion line must be perpendicular with the pipe surfaces to within  $\pm 5^\circ$  (A) for any pipe wall greater than 7.9 mm (0.312 in.) and  $\pm 10^\circ$  for pipe with wall thickness equal to or less than 7.9 mm (0.312 in.).
  - f) The distortion angle  $\Theta$  of the metal flow due to squeeze roll forging pressure must be within the qualified limits ([Annex B.6, Figure 11](#)), as measured with respect to the pipe wall centerline ( $\Theta_{OD}$  &  $\Theta_{ID}$ ),
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perpendicular to the fusion line. The distortion angle shall be determined (four locations) near a position equivalent to one-fourth wall thickness ( $\frac{1}{4} \times wt$ ,  $\theta_{OD}$ ) and three-fourths wall thickness ( $\frac{3}{4} \times wt$ ,  $\theta_{ID}$ ) from the O.D. surface on both sides of the weld seam. During qualification and production of a particular line item (same grade, O.D., w.t.), the O.D. and I.D. distortion angles shall always be measured at the same distance (L) from the fusion centerline, as established during qualification for average O.D. and I.D. metal distortion angles. The location of L for angle measurement shall be at the outer region ( $\frac{1}{4} \times wt$ ,  $L_{OD}$ ) of the welding heat tint zone, with a tolerance of  $\pm 3\%$  of the wall thickness. The distance  $L_{OD}$  for the O.D. angles  $\theta_{OD}$  may be different from the distance  $L_{ID}$  ( $\frac{3}{4} \times wt$ ) angle for the  $\theta_{ID}$ , but each shall be given in the qualification report.



**Figure 10 - Metal Flow Angle**

- $\theta_{OD}$  - Angle of metal flow distortion on O.D. side
- $\theta_{ID}$  - Angle of metal flow distortion on I.D. side
- A - Angle of fusion line measured from perpendicular to O.D. surface
- WT - Pipe wall thickness

**Note:** Various techniques can be used for revealing and measuring metal flow distortion. Some methods that have proven successful individually or in combination include: 1) saturated picric acid etchant in distilled water, 2) take specimens from a small pipe sample in which the seam has not been heat treated, 3) use of an optical comparator or profile projector.

*Commentary Note:*

*Figure 1 through Figure 9 - c) are in the base specification, [API SPEC 5L](#).*

### Hardness Tests

Frequency and sample preparation for hardness tests shall be as described in 10.2.5.5 above. The same samples can be used for both the weld

microstructure tests and the hardness tests. Vickers hardness testers shall be used.

Hardness traverses shall be made  $1.5 \text{ mm} \pm 0.5 \text{ mm}$  from the I.D. and O.D. surfaces and at the mid-wall. Each traverse shall consist of at least the following: one indentation in the center of the weld area, one indentation located not more than 1.0 mm on each side of the central indentation, and one indentation in the parent metal outside of the normalized zone on each side of the weld. (Total of 5 indentations in each traverse.) For each traverse, the middle three measurements should be in the normalized zone and encompass the weld seam.

The maximum hardness measured shall not exceed 248 HV (Vickers Hardness using a 10 kg load) and the average hardness of the middle three I.D. measurements shall not exceed the average hardness of the corresponding three O.D. measurements as shown by a statistical test of data from two samples with unequal variances for a 95% confidence level.

#### 10.2.6 Hydrostatic Test

The seam shall be positioned in the upper quadrant (approximately 12:00 o'clock) prior to the application of pressure. Any pipe whose seam is not in the upper quadrant during pressure testing shall be re-tested. Any failing or leaking pipes shall be rejected and the cause investigated and corrective actions documented. The lighting in the hydrostatic test area shall provide a minimum illumination of 500 lux [modification].

Test pressures shall be held for at least 10 seconds.

10.2.6.7 Required test pressure shall be determined using minimum wall thickness ( $t_{\min}$ ) and a hoop stress of at least 95% (100% for Class C services) of the specified minimum yield strength of the pipe [modification].

#### 10.2.7 Visual Inspection

10.2.7.1 The lighting in the visual inspection shall provide a minimum illumination of 500 lux [modification].

#### 10.2.11 Sorting and Reprocessing [modification]

Reprocessing per Annex N or paragraph 9 of [ISO 404](#) is not allowed. If either of the retest per [ISO 404](#) fails, the entire test unit shall be rejected or sorted by testing each pipe per paragraph 9 of [ISO 404](#).

## 10.2.12 Retesting

Retesting shall be in accordance with [ISO 404](#). Retesting requirements in Annex N shall not apply.

The following retest criteria apply to rejects due to welding outside the qualified process limits ([Annex B.6](#), [Figure 11](#)):

- a. Single pipes rejected while manufacturing to 8.3.6 2.a shall not be retested.
- b. Production test units rejected while manufacturing to 8.3.6 2.b may be retested in the following manner for the process variable in question.
  - 1) Test 13 additional pipe lengths from the test unit rejected and perform all testing required by 10.2.4.7 and 10.2.5.
  - 2) For test units that were rejected for excessive or insufficient heat input: If all flattening and metallographic results, for the sample group of 13, are acceptable, accept the test unit with no further processing. If the results are not acceptable, either reject the test unit, finally, or test each remaining pipe in the test unit and reject those lengths that exhibit unacceptable results. Those pipes exhibiting acceptable results form the remainder of the test unit which shall be accepted.
  - 3) For test units that were rejected for excessive or inadequate metal distortion angle (see [Annex B.6](#) 3.): If all flattening and metallographic results are acceptable for the retested pipes, accept the test unit with no further processing. If metal distortion angle of the sample is still found unacceptable calculate the average OD and ID angles ( $\bar{X}_{13}$ ) and the associated standard deviations ( $S_{13}$ ) for each. If either of the following calculations is false reject the test unit, finally:
    - i)  $|\bar{X}_{13} - \mu| \times 3.606 / S_{13} \leq 2.179$
    - ii)  $12 \times S_{13}^2 / \sigma^2 \leq 19.68$

## 11 Marking

### 11.1 General [addition]

11.1.4 Marking of pipes shall be in USC units in accordance with Annex O with the additional requirements listed below. Annex N, wherever referred to, shall apply. The area of the pipe to be marked shall be clean and dry.

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The markings shall be paint stenciled using a medium and protective varnish that will provide a legible marking for at least one year of outside storage. The varnish coating shall be hard drying and the dry film thickness should not exceed 50 micrometers. The size of the lettering shall be commensurate with the diameter of the pipe, but in no case less than 0.75 inch (0.59 inch for diameter 6 inches and smaller) and in height for API markings and 13 mm in height for shipping markings.

#### 11.1.5 Marking of Non-sour Service Pipe

Pipe purchased for non-sour service shall be identified by painting a white longitudinal stripe, 2 inches wide by 18 inches long, on the inside surface of both ends. For seamless pipes, the stripe can be marked on the inside or outside surface. This stripe is intended to provide identification until the pipe is installed.

#### 11.2 Pipe Markings [modification]

- 11.2.1 k) Each pipe shall be marked Saudi Aramco, followed by the destination, Purchase Order number/Item Number, heat number, and the Saudi Aramco 9COM or 9CAT stock number. If there is no assigned 9COM or 9CAT stock number, the pipe shall be marked “01-SAMSS-333 Class B or C (as appropriate).”

#### 12 Coating and Thread Protectors [modification]

Pipe shall be supplied without mill coating unless specified otherwise in the Purchase Order. Varnish coating of the markings is acceptable provided that the varnish is hard drying with a maximum dry film thickness of 0.050 mm.

#### 14 Pipe Loading [modification]

Saudi Aramco Materials System Specification [01-SAMSS-024](#) shall be followed.

#### Revision Summary

28 August 2013

Major revision to align with API SPEC 5L 45<sup>th</sup> edition.

## **Annex B – Manufacturing Procedure Qualification for PSL 2 Pipe**

### **B.0 Introductory Note [addition]**

All pipes must be manufactured using a qualified Manufacturing Procedure that has been approved by Saudi Aramco Consulting Services Department (CSD) / Capital Program Support Division (CPSD) / Materials Engineering & Corrosion Project Support Group (ME&CPS). Procedure submittals include B.3 and B.4 requirements. The Manufacturing Procedure shall be qualified prior to start of main production and submitted no later than five days after start of main production. Fax or email submittals are acceptable. Final acceptance of pipe is contingent upon successful qualification of a procedure and approval by Materials Engineering & Corrosion Project Support Group (ME&CPS), plus evidence that the pipe was manufactured within the limits of the Manufacturing Procedure.

The manufacturer may use a previously qualified Manufacturing Procedure if the new product falls within a set of previously qualified essential variable groups listed below. In this case, the submittal should be in the form of a Manufacturing Procedure Specification with simplified B.3 information and without the detailed supporting test data that was previously submitted. The manufacturing procedure shall be requalified any time there is a change in the essential variables. If the essential welding variables (Annex B.5) change, but the essential manufacturing variables are unchanged, then only the welding conditions (Annex B.5) must be requalified.

Essential manufacturing variables:

- a) Pipe grade
- b) Outside diameter group
  - 1) Up to and including 323.9 mm (NPS 12)
  - 2) Over 323.9 mm (NPS 12)
- c) Wall thickness group
  - 1) 6 mm to 11 mm
  - 2) Over 11 mm

## **B.5 Manufacturing Procedure Qualification Tests [modification]**

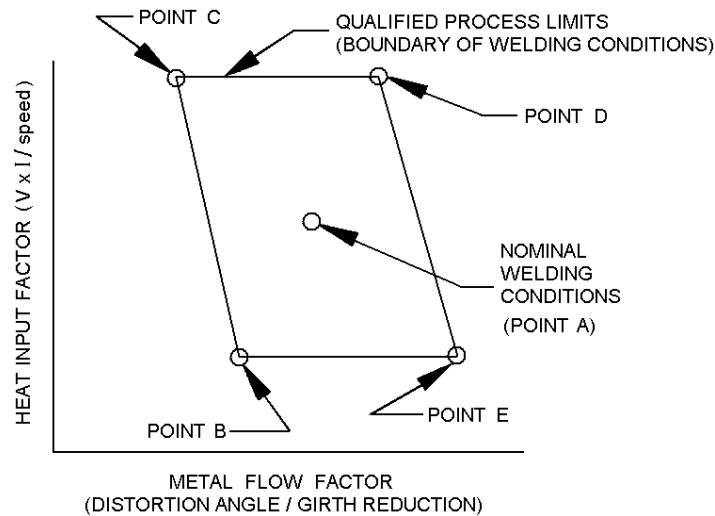
Manufacturing procedure qualification test results to be submitted include:

- a) All tests required in Section 10. A complete series of tests shall be performed on at least one pipe from each coil described in B.6.3.c. If multiple welding lines will be used for production the same requirements shall apply to each pipe manufacturing line.
- b) HIC and SSC test results as per annex H and DWT test results as per [Annex G](#), if applicable.
- c) Results of SSC test and grooving corrosion test (applicable only for Class C sour service).
- d) Welding qualification as specified in [Annex B.6](#).
- e) For the purpose of the first-time qualification only (Paragraph 8.1.1) the submittal may be based upon Annex B.1, B.3, mill historical production data, and the mill's own process control procedures. However, the quantity and quality of the information submitted must be sufficient to confirm compliance with the intent of this specification. If a purchase order is awarded on this basis, the specific qualifications required by Annex B.5 and B.6 shall be submitted and approved prior to start of main production.
- f) SPC Procedure if CEPC method is used for control of only heat input process variables. See Paragraph 8.3.6.2.b.
- g) Description of CEPC. See paragraph 8.3.6.2.a.
- h) Postproduction Process Control Report (see 8.1.1) for a previous order, either a) the last order, or preferably b) the last order with the same essential welding variables (see [Annex B.6](#)).

## **B.6 – Qualification of Welding Conditions [addition]**

1. Essential welding variables:
    - a) Pipe grade
    - b) Service Class (MPQ for Class C qualifies Class B but not vice versa)
    - c) Nominal diameter
    - d) Specified wall thickness  $\pm 1.0$  mm
    - e) Operation within qualified process limits ([Figure 11](#))
    - f) Contact tip/roller alloy composition (HFERW only)
-

- g) Induction coil configuration (HFI only)
  - h) Impeder configuration (HFI only)
2. Process variables:
- a) Heat Input Factor (function of wall thickness, voltage, current, temperature, and line speed)
  - b) Metal Flow Factor (distortion angle ÷ girth reduction at squeeze roll)
  - c) Seam annealing power (related to temperature)
  - d) Seam anneal width at I.D. surface
3. Qualification Steps
- a) Install chart recorders, or other appropriate devices, for electronic data acquisition to monitor and control the process heat input variables (Process variable #1 above).
  - b) From the nominal settings for **voltage, current (and/or power), line speed, and metal flow factor (distortion angle ÷ girth reduction)** identify, or calculate the maximum and minimum limits for each and construct the preliminary process limits (see [Figure 11](#)).
- Note: The boundary limits may be based on experience (such as data from a previous order), or calculated, or chosen arbitrarily.*
- c) Produce at least one coil at the nominal welding conditions and one coil at each of the chosen maximum and minimum limit points, determined in B.6.3.b) above, and depicted in [Figure 11](#).
    - i. Sample each coil at the front, middle, and end.
    - ii. Evaluate each sample for compliance with 10.2.4.6 (guided-bend test), 10.2.4.7 (flattening test) and 10.2.5 (metallographic examination).
    - iii. If any set of specimens fails to meet the requirements above, adjust the variable settings accordingly and produce another coil. If necessary continue adjustments until the desired limits of the process have been identified.
    - iv. Choose, at random, one additional pipe from the coil at nominal welding condition of point A in [Figure 11](#) and remove at least 10 samples, at least one meter apart, for metallographic tests in accordance with 10.2.5.5.f.
-



**Figure 11 - Manufacturing Process Boundary Limits**

4. [Figure 11](#), in terms of 8.3.6.2.a, represents the limits within which CEPC must control the processes.
5. Perform the following calculations with the measurements made in 10.2.5.5.f for all five test coils.
  - a) Determine the average overall metal distortion angle for all O.D. angles combined. This calculated value is defined as  $\bar{X}_{QOD}$ .
  - b) Determine the standard deviation for all O.D. angles combined. This calculated value is defined as  $S_{QOD}$ . If  $S_{QOD} > 3.0$ , the process must be requalified after process improvements have been made.
  - c) Determine the average overall metal distortion angle for all I.D. angles combined. This calculated value is defined as  $\bar{X}_{QID}$ .
  - d) Determine the standard deviation for all I.D. angles combined. This calculated value is defined as  $S_{QID}$ . If  $S_{QID} > 3.0$  the process must be requalified after process improvements have been made.
  - e) Determine, for the additional single pipe from coil A, the average O.D. and I.D. angles with their associated standard deviations. These values ( $\bar{X}_{AOD}$ ,  $\bar{X}_{AID}$ ,  $S_{AOD}$ , and  $S_{AID}$ ) are defined as approximations of the true process means and standard deviations and shall appear in the qualification report. If  $S_{AOD}$  or  $S_{AID}$  are greater than  $S_{QOD}$  or  $S_{QID}$ , respectively, requalification shall be required after significant process improvement.

6. The final process capability curve ([Figure 11](#)) represents the qualified process limits for the Manufacturing Procedure and combination of essential welding variables. Any operation shown to be outside of the Qualified Process Limits will require evaluation by CSD or requalification, and any pipe produced outside this qualified boundary must be either rejected or held for further evaluation.
  - a) For pipe manufactured with full CEPC (see 8.3.6.2.a) the CEPC system shall control process variables within the area bounded in [Figure 11](#) in accordance with 8.3.6.2.a.
  - b) For pipe manufactured to 8.3.6.2.b. the distortion metal angle tests taken in accordance with 10.2.5.5 shall be SPC charted in accordance with [ISO 7870-2](#). A production test unit shall be rejected if the sub-group plot falls outside of the UCL or LCL.
7. The pipe used for qualification may be included in the production order provided that each coil is sampled and tested as described in B.5.3 above. Any coil that does not pass all of the tests shall be rejected.

## **Annex E – Non-Destructive Inspection for other than Sour Service or Offshore Service**

- E.1 Qualification of Personnel [modification]
- E.1.3 Level 1 personnel may set up the equipment, perform tests, and report the results. Supervision of Level 1 personnel and interpretation of results shall be done by Level 2 employees. The primary Level 3 employee such as company employee, outside consultant, or third party inspector shall be certified in accordance with [ASNT CP-189](#) or [EN 473](#) or [ASNT SNT-TC-1A](#) or by an independent certifying body acceptable to Saudi Aramco. Working practice for qualification shall be submitted to Saudi Aramco for approval.
- E.3 Methods of Inspection
- E.3.1.3 b) Timing of NDT operations [modification]
- Ultrasonic examination of the weld seam shall be carried out after hydrostatic testing. Means shall be provided to mark the pipe when the ultrasonic inspection equipment indicates an imperfection is present so that defective areas can be identified.
- E.3.2 Pipe end inspection – Welded pipe [modification]
- E.3.2.1 For manual testing, the scanning speed shall not exceed 150 mm/s.
- E.3.2.3 Verification shall be carried out in accordance with [ASTM A578](#) and [ASTM A435](#) or [ISO 11496](#).
- E.5 Ultrasonic and Electromagnetic Inspection
- E.5.1 Equipment [modification]
- E.5.1.1 Test method based on electromagnetic principles is not acceptable for testing of the weld seam
- E.5.5 Acceptance limits [modification]
- E.5.5.1 The acceptance limit for indications produced reference indicators shall be N10 notch for liquid service and N5 notch for gas service.
- E.8 Lamellar imperfections in the pipe body of EW, SAW and COW pipes [modification]
- Verification of compliance shall be carried out.
-

E.9           Laminar imperfections along the strip/plate edges or pipe weld seam of  
EW, SAW and COW pipes [modification]

Verification of compliance shall be carried out.



## Annex G – PSL 2 Pipe with Resistance to Ductile Fracture Propagation

### G.1 Introduction [modification]

This annex is invoked when additional fracture toughness is required to control ductile fracture propagation in gas lines and liquids lines with a high vapor pressure.

It is applicable to pipe with wall thickness of 0.25 inch to 1.5 inches for use in cross-country pipelines, offshore pipelines, flowlines, and trunklines at design temperatures above 0°C.

### G.1.3 Definition of Class IV Service [addition]

*Class IV Service: This class is for gas, two-phase flow, and liquid lines such as NGL, whose vapor pressure exceeds 690 kPa (100 psia).*

*Commentary Note:*

*Reference to Class I service has been discontinued because PSL 2 pipe ordered to this specification meets the requirements for Class I service by default.*

G.1.4 This annex is applicable only if the line pipe classification is specified as class IV in the purchase order [addition].

### G.2 Additional Information to be Supplied by the Purchaser [modification]

G.2.1 Paragraph a) shall be applicable for all purchase orders.

G.2.2 a) CVN impact test temperature shall be at 0°C.

b) DWT test temperature shall be at 0°C.

### G.3 Acceptance Criteria [modification]

G.3.1 All parent metal Charpy fracture surfaces for all diameters shall exhibit at least 85% average and 75% minimum shear per each set of test.

G.3.2 Minimum average Charpy impact energy value shall be as specified by the Buyer in the relevant requisitions, quotation requests, and purchase orders as per [SAES-L-131](#). CVN test shall include weld and base metal.

*Commentary Note:*

*Saudi Aramco Engineering Standard [SAES-L-131](#) is for reference for Saudi Aramco personnel only. This standard is not applicable to pipe manufactures.*

- G.3.4 For DWT test, specimens shall not exhibit less than 85% average and 75% minimum shear per each set of test.

*Commentary Note:*

*Each specimen must tear completely to give a readable fracture surface as shown in [API RP 5L3](#) Figure 5 and Appendix A. Specimens that buckle, collapse, deform or rip are considered invalid and the test must be performed again. Specimens must be firmly mounted to promote acceptable test results.*

- G.4 Test Frequency [addition]

- G.4.3 Specimen Orientation

All specimens shall be oriented transverse to the rolling direction. The orientation specified in Table 20 shall apply.

## Annex H – PSL 2 Pipe Ordered for Sour Service

### H.4 Acceptance Criteria

#### H.4.1 Chemical Composition [modification]

Chemistry restrictions outlined in paragraph 9.2.2 shall apply.

For C.E./Pcm values, the more stringent of the values stipulated in Table H.1 and paragraph 9.2.2 of this specification shall apply.

#### H.4.3 HIC/SWC Test [modification]

- b) Crack length ratio (CLR)  $\leq 10\%$
- c) Crack thickness ratio (CTR)  $\leq 3\%$

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 1 mm from the inner and outer pipe 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 pipe 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.

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

#### H.4.4 Hardness Test [modification]

Requirements stated in 10.2.5.5 shall be followed. Maximum acceptable hardness, including weld cap, is 248 HV using 10 kg load.

H.4.5 SSC Test [modification]

The results of the tests at 0.90 of actual yield strength (See H.7.3.2) shall be described and reported pass/fail, but for information only. The following acceptance criteria shall be applied to the specimens tested at 0.80 of actual yield strength and all three specimens must pass:

After removal from the solution, the specimen shall be stressed to more than the actual yield strength. The specimen shall not break and no cracks shall be visible at 10X magnification.

H.4.6 Special requirements for grooving corrosion resistance [addition]

A test for grooving corrosion resistance shall be performed as part of the manufacturing procedure qualification (See [Annex B](#)) for Class C services only. This test is required only when steel is being used from a particular steel mill for the first time for Class C sour service. The test method shall be that described in Section 2 of the PRCI Final Report for PR-15-9306 “Susceptibility of Modern ERW Pipe to Selective Weld Seam Corrosion in Wet Environments.” (See [www.prci.com](http://www.prci.com)) The test environment shall be room temperature synthetic seawater ([ASTM D1141](#)) in equilibrium with 30 psia CO<sub>2</sub>. The acceptance criterion is that the grooving factor GF (weldline corrosion/general corrosion, see Figure 12) shall not exceed 1.5.

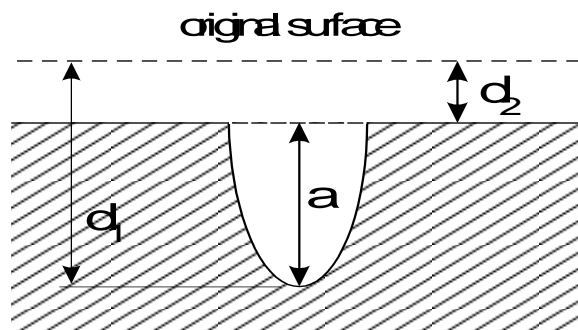


Figure 12

$$GF = d_1/d_2 = 1 + a/d_2$$

H.5 Surface Conditions, Imperfections and Defects [modification]

H.5.2 Hardness exceeding 248 HV, even on the external surface, shall be considered as unacceptable.

## H.7 Inspection

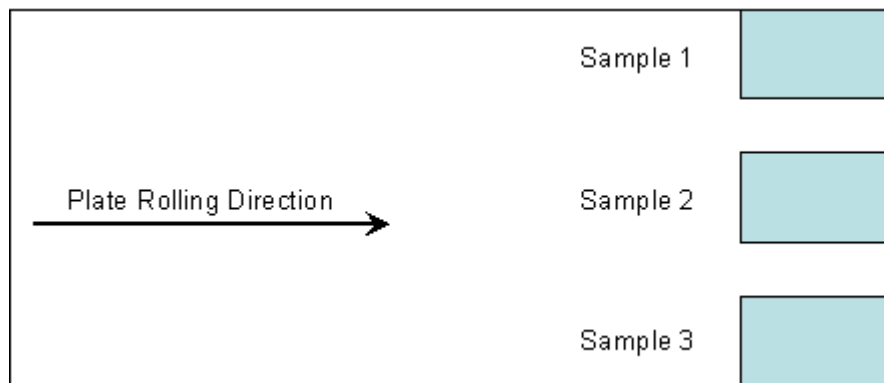
### H.7.1 Specific Inspection [modification]

The frequency of inspection for HIC test shall be one pipe from each of the first three heats supplied by each mill from each purchase order shall be tested and one pipe out of every five subsequent heats. The pipes for testing can be selected by the purchaser's representative from the heats containing the higher sulfur content. One set of three specimens is required for HIC testing.

### H.7.2 Samples and Test Pieces for Mechanical and Technological Tests [modification]

#### H.7.2.2 In addition to testing on the pipe, testing on the raw material (coil) shall be performed as follows:

- 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 2).
- If several thicknesses are produced from a single heat, then the thinnest shall be tested.



**Figure 2 – Plate Sampling Location Diagram**

### H.7.3 Test Methods [modification]

#### H.7.3.1.1 The following shall be included in the HIC test report

- a) The CLR results of the control sample
  - b) Location and dimensions of coupons, and whether taken from pipe or coil.
-

- c) pH of H<sub>2</sub>S saturated solution at the start and end of the test.
- d) Chemical composition of material tested, including Al, B, C, Ca, Cr, Cu, Mn, Mo, Ni, Nb, N, P, Si, S, Ti and V.
- e) Results of cracking evaluation.
- f) Photomicrographs of metallographically-polished (1 micron finish)
- g) Specimens of typical parent material microstructures on a plane with the same orientation as that used for cracking evaluation.
- h) Parent material microstructure

H.7.3.1.4 The CLR results of the control sample shall also be reported. For each section containing cracks, a photograph shall be taken of the complete cross-section.

H.7.3.1.5 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.

H.7.3.1.6 The purity of the H<sub>2</sub>S gas shall be 99.5% minimum. H<sub>2</sub>S gas generated from chemical reactions, e.g., Kipps apparatus, is not acceptable as a source of H<sub>2</sub>S gas.

H.7.3.1.7 Should the Vendor's HIC test results be rejected by Saudi Aramco, re-testing may be referred to an independent 3<sup>rd</sup> party laboratory acceptable to Saudi Aramco for resolution. This laboratory shall use HIC test methods and control samples in accordance with this specification.

H.7.3.1.8 Testing shall be performed by the Manufacturer/Vendor or 3<sup>rd</sup> party laboratory acceptable to Saudi Aramco. The Chairman or Vice Chairman of the Materials and Corrosion Control Standards Committee shall approve all HIC Test Laboratories following the review of the Vendor Inspection survey report. This report shall include the mandatory requirements specified below:

- a. Verify the Inspection and Testing Requirements specified in Form [175-010210](#) HIC Testing are completely satisfied. This task shall be carried out by Saudi Aramco Inspection Representative, e.g., Vendor Inspection Division.
  - b. 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.
-

- c. The purity of the H<sub>2</sub>S gas shall be 99.5% minimum. H<sub>2</sub>S gas generated from chemical reactions, e.g., Kipps apparatus, is not acceptable as a source of H<sub>2</sub>S gas.
- d. H<sub>2</sub>S concentration shall be measured by iodometric titration as per the current [NACE TM0284](#), 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).
- e. The HIC testing laboratory shall provide documentation supporting the adequate training of technicians or engineers undertaking the evaluation of CLR and CTR measurements.
- f. Should the Vendor's HIC test results be rejected by Saudi Aramco, re-testing may be referred to an independent 3<sup>rd</sup> party laboratory acceptable to Saudi Aramco for resolution. This laboratory shall use HIC test methods and control samples in accordance with this specification.
- g. 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, or pipes.
  - Purity of the utilized salts and H<sub>2</sub>S 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 3<sup>rd</sup> party laboratory meeting Saudi Aramco's approval.

H.7.3.1.9 HIC test verification shall be in accordance with Saudi Aramco Inspection Form [175-010210](#) Inspection and Testing Requirements – HIC Testing.

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#### H.7.3.1.10 Retesting Requirements

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

- a) The coil or pipe that failed the test shall be rejected. However, two additional joints of pipe (or pieces from coil) may be selected at random from the same heat for further testing. If both of the retest groups pass, all pipes 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.

H.7.3.1.11 Additional testing shall be required if the steel-making and/or pipe-making procedures are significantly altered during production [addition].

#### H.7.3.2 SSC Test [modification]

Three samples shall be tested at 0.80 of the actual measured yield strength and three samples shall be tested at 0.90 of the actual measured yield strength. See H.4.5 for the acceptance criteria.

#### H.7.3.3 Hardness Test [modification]

H.7.3.3.1 Only Vickers hardness testers shall be used. The maximum hardness measured shall not exceed 248 HV using 10 kg load.

H.7.3.3.3 Hardness test locations shall be as per 10.2.5.5 of this specification.



## **Annex J – PSL 2 Pipe Ordered for Offshore Service**

### J.4.1 Chemical Composition [modification]

The requirements of paragraph 9.2.2 above shall apply in addition to the requirements given in Table J.1.

### J.4.3 Hardness Test [modification]

The requirements in paragraph 10.2.5.3 above shall apply.

### J.8.2.3 Samples for hardness tests [modification]

The requirements in paragraph 10.2.5.3 above shall apply.

### J.8.3.2 Samples for hardness tests [modification]

The requirements in paragraph 10.2.5.3 above shall apply.

### J.8.4 Non-destructive Inspection [modification]

The modifications to Annex K stated below shall apply.

## **Annex K – Non-destructive Inspection for Pipe Ordered for Sour Service and/or Offshore Service**

- K.4 Non-destructive inspection of HFW pipe
- K.4.1 Non-destructive inspection of weld seam [modification]
- Inspection shall be done as per ISO 10893-11 with acceptance level U2/U2H or ISO 10893-10 with acceptance level U2.
- K.4.2 Laminar imperfections in the pipe body
- This requirement is mandatory. The coverage of lamination detection shall be at least 25% of the strip/plate or pipe surface.
- K.4.3 Laminar imperfections on the strip/plate edges or areas adjacent to the weld seam
- This requirement is mandatory.