API Ballot id# 6450
SC5 TG LP

Work Item Number	4246
Title of Work Item	Field Girth Weldability Testing
Ballot Revision Level	2
Type of Ballot (Initial, Comment, Comment resolution (reference API ballot#), 1st Re-ballot, 2nd Re-ballot, etc.)	Re-ballot Previous Ballot ID: 6206
Submitter Name(s)	Alex Afaganis, Gilmar Zacca Batista
API Document Modified	5L_e46
Revision Key	The " ****** " indicates there is unaltered content above/below.

Work Item Charge: Develop an annex for weldability testing of line pipe manufactured in accordance with API Spec 5L. The intent is to demonstrate that the line pipe is suitable for field girth welding processes.

Ballot Rationale: The Annex will provide a standardized practice for performing weldability testing on line pipe, including provisions for demonstrating properties in pipe at weld heat affected zone (HAZ).

Ballot Text: Draft document attached.

NOTE: Ballot 6206 comment resolutions are included as supplemental information.

API Ballot

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Line Pipe

API SPECIFICATION 5L

FORTY-SIXTH EDITION, APRIL 2018

API MONOGRAM PROGRAM EFFECTIVE DATE: MAY 1, 2019

ERRATA 1, MAY 2018

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******

7 Information to be Supplied by the Purchaser

******

7.1 General Information

The purchase order shall include the following information:

…….

h) confirmation of applicability of individual annexes (with additional agreements often defined therein).

7.2 Additional Information

The purchase order shall indicate which of the following provisions apply for the specific order item:

……

c) Items that apply, if agreed:

……

17) girth weldability data or tests for PSL 2 pipe (see 9.15 and Annex X) and additional information to be provided by the purchaser;

******

9 Acceptance Criteria

******

9.15 Weldability of PSL2 Pipe

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If agreed, girth weldability testing shall be in accordance with Annex X.

******

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Annex B
(normative)

Manufacturing Procedure Qualification for PSL 2 Pipe

B.5 Manufacturing Procedure Qualification Tests

B.5.4 If agreed, weldability test shall be in accordance with Annex X. ~~The purchaser may ask for characteristic data on other properties (e.g. weldability) of the product.~~

~~NOTE Purchaser requests for weldability data on particular steel grades can require specific weldability testing to be conducted; in such instances, it is the responsibility of the purchaser to supply the manufacturer with details of the welding processes and parameters for which weldability data are required; it is important to consider weldability testing of newly developed steel grades such as L690 or X100 and L830 or X120 where data are otherwise unavailable.~~

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Annex X
(normative)

Girth Weldability Testing

X.1 Introduction

This annex specifies additional girth weldability testing requirements for API 5L PSL 2 pipe [see 7.2 c) 17)].

The intent of the weldability test is to verify if acceptable properties in the field girth weld HAZ are obtainable. This is not the field welding procedure to be used; however, such information may be used to aid the development of the field welding procedure. To this end, the pipe material should be tested to cover typical or a range of heat input energies generally utilized in subsequent pipe utilization. This document gives four options which can be selected individually to cover ranges typically used.

NOTE Depending on the welding process and procedure used during the weldability test, the effects on the properties of the pipe materials can have conflicting aims (e.g., toughness and hardness).

X.2 Additional Information to be Supplied by the Purchaser

In addition to items a) to c) as specified by 7.2, the purchase order shall also indicate which of the following provisions apply for the specific order item:

a) Items that are subject to mandatory agreement, if applicable:

   1) alternate weldability data (X.3.3.4);

   2) alternate evaluation details (X.4.3 and X.6.1);

   3) average hardness for moderate and high heat input evaluation (X.5.4.3).

b) Items that apply as prescribed, unless otherwise agreed:

   1) pipe grades grouping (X.3.3.3);

   2) welding process (X.4.1.4);

   3) heat Input (X.4.2.1; X.4.2.2 and X.4.2.3);

   4) CVN Impact and CTOD acceptance criteria (X.5.2.1 and X.5.3.1);

   5) hardness acceptance criteria (X.5.4.1 and X.5.4.2);

   6) CVN Impact and CTOD test temperature (X.6.3.1 and X.6.3.2.2);

   7) Load for microhardness test (X.6.3.3.2).

c) Items that apply, if agreed:

   1) material format (X.3.4.1.2);

   2) purchaser approval of heat analysis (X.3.4.2.4);

   3) sample heat treat condition (X.3.4.3);

   4) material strength (X.3.4.4).

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X.3 Material for Weldability Test

X.3.1 Manufacturing Procedure Qualification

The pipe material shall be qualified in accordance with the manufacturing procedure qualification (see Annex B) and within the limits specified (see B.5), as applicable.

X.3.2 Weldability Test-type

In addition to the requirements of 7.1, the purchase order shall indicate if any of the weldability test-type provisions from below apply for the specific order item:

a) low heat input evaluation;

b) moderate heat input evaluation;

c) high heat input evaluation;

d) alternate evaluation.

X.3.3 Applicability

X.3.3.1 The weldability tests shall be conducted for each applicable delivery condition (Table 3).

X.3.3.2 The maximum pipe wall thickness variation from the nominal qualified shall be:

a) +10% / - unlimited, for wall thickness ≤ 12.7 mm (0.500 in);

b) +10% / -25% (or down to 12.7 mm or 0.500 in), for wall thickness > 12.7 mm (0.500 in).

X.3.3.3 Pipe grades X52 (L360) and X56 (L390) may be grouped. Grades X60 (L415) and above shall be tested individually.

NOTE: Weldability tests should not be considered necessary for grades X46 and below.

X.3.3.4 If agreed, the manufacturer shall supply weldability historical data in lieu of performing weldability tests.

X.3.4 Material Details

X.3.4.1 Format

X.3.4.1.1 The material shall be taken from steel plate/coil or pipe.

X.3.4.1.2 If agreed, weldability tests shall be performed on the finished pipe.

X.3.4.2 Composition

NOTE The behavior of the steel during and after welding is dependent not only on the steel composition, but also on the hot rolling/cooling processes, pipe forming, welding process, heat input, pre-heat/interpass temperatures used and the conditions for preparing for, and carrying out, welding.

X.3.4.2.1 For *low* heat input evaluation, the material shall be selected such that the CE_{Pcm} is no *less* than 0.02 % below the maximum carbon equivalent CE_{Pcm}; or the CE_{IIW} is no less than 0.03 % below the maximum carbon equivalent CE_{IIW}. The CE_{IIW} or CE_{Pcm} shall be based on the heat analysis.

X.3.4.2.2 For *moderate* and *high* heat input evaluation, the material shall be selected such that the CE_{Pcm} is not greater than 0.02 % above the minimum carbon equivalent CE_{Pcm}; or the CE_{IIW} is not greater than 0.03 % above the minimum carbon equivalent CE_{IIW}. The CE_{IIW} or CE_{Pcm} shall be based on the heat analysis.

NOTE Minimum/maximum CE_{IIW} or CE_{Pcm} may not be specified in this specification, so the range may be based upon the actual production or the applicable purchaser supplemental specification. The maximum/minimum CE levels for weldability material test selection may be lower/higher (as applicable) than specified in this specification based on manufacturer design or purchaser supplemental specification.

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X.3.4.2.3 If moderate or high heat input tests as well as low heat input tests are required, the purchaser and manufacturer shall agree on acceptable composition ranges.

X.3.4.2.4 If agreed, the purchaser shall approve the heat analysis of the steel to be used for the weldability tests.

X.3.4.3 Heat Treatment Condition

If agreed, a heat treatment may be applied to the plate/coil/pipe to simulate the thermal history of the pipe coating.

X.3.4.4 Material Strength

If agreed, material from the high end of strength range shall be used for weldability testing.

X.4 Test Welds

X.4.1 General

X.4.1.1 Heat input calculation shall be made according to Equation X.1:

$$HI = \eta \times [(V \times I \times 60) / (1000 \times v)] \quad \text{(X.1)}$$

where

HI = heat input (kJ/mm or kJ/in)

η = process efficiency: 0.8 for SMAW, FCAW and GMAW; 0.6 for GTAW; 1.0 for SAW

V = voltage (V)

I = amperage (A)

v = travel speed (mm/min or in/min)

NOTE Field girth welding procedures do not typically incorporate a process efficiency factor because welding process is controlled as an essential welding variable. In these cases, the reported heat input calculated by Equation (X.1) needs to be divided by the relevant process-specific efficiency factor (η) to compare it to field welding procedures that do not incorporate a process efficiency factor for calculation of heat input.

X.4.1.2 The heat transfer efficiency is already considered in some welding machines output. In these cases, the heat input calculation shall be done without consider the welding process efficiency.

X.4.1.3 Wave form controlled welding is permitted provided heat input is calculated using instantaneous power or instantaneous energy.

X.4.1.4 Welding Process

Unless otherwise agreed, the weldability tests shall be done with a single arc process, except that a different arc process may be used for the root pass. Any welding process may be used provided the specified heat input (X.4.2.1, X.4.2.2 or X.4.2.3, as applicable) is achieved.

X.4.1.5 Bevel Configuration

The test coupon shall be prepared with at least one square cut (0°) bevel or a groove profile such that will result in a straight side (for testing). The other side may be prepared with angled or square bevel(s) such as the examples shown in Figure X.1.

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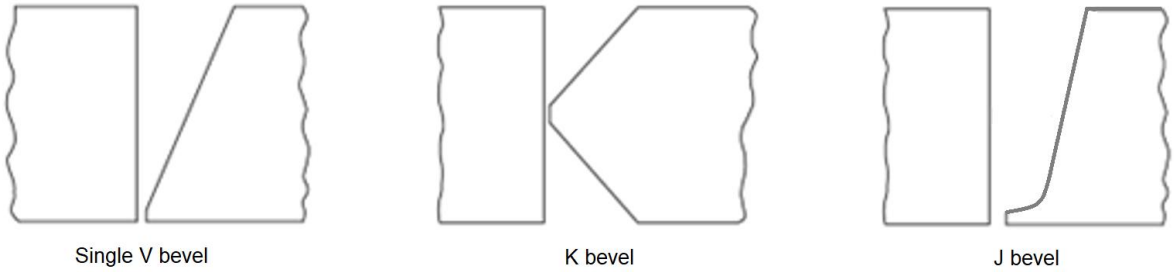

Figure X.1—Examples of Bevel Preparation

X.4.1.6 Consumables

The weld shall be fabricated using consumables that meet or exceed the minimum strength of the pipe/plate material.

NOTE Excessive weld metal overmatching can reduce the measured HAZ CTOD values by increasing constraint on the HAZ.

X.4.1.7 Coupon Dimensions

For plate/coil welding the weld length produced for each configuration shall be a minimum of 610 mm (24 in.). Each coupon width shall be a minimum of 305 mm (12 in.) for a final width of 610 mm (24 in.).

For pipe welding, rings shall be a minimum length of one pipe diameter or 305 mm (12 in), whichever is shorter.

X.4.2 Heat Input

X.4.2.1 Low Heat Input Evaluation

The tests shall be carried out with a heat input less than 0.8 kJ/mm (20 kJ/in), preheating temperature of 50 °C ± 5 °C (125 °F ± 9 °F) and maximum interpass temperature of 200 °C (390°F) for all welding passes.

X.4.2.2 Moderate Heat Input Evaluation

The welds shall be fabricated using a 1.5–2.0 kJ/mm (38-50 kJ/in) heat input with a preheat of 120 °C (± 20 °C) (250 °F ± 36 °F) and a maximum interpass temperature of 200 °C (390°F).

X.4.2.3 High Heat Input Evaluation

The welds shall be fabricated using a 2.5–3.0 kJ/mm (65-75 kJ/in) heat input with a preheat of 120 °C (± 20 °C), (250 °F ± 36 °F) and a maximum interpass temperature of 300 °C (570°F).

NOTE Preheat temperature is the minimum temperature of the base material in the volume surrounding the point of welding immediately before welding is started. In a multipass weld, it is also the minimum interpass temperature immediately before the second and subsequent passes are started.

X.4.3 Alternate Evaluation

Details such as frequency, welding process, bevel configuration, consumables, heat input, preheat temperature, inter-pass time/temperature, and coupon dimensions shall be agreed between purchaser and manufacturer.

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X.5 Acceptance Criteria

X.5.1 Tension Test

X.5.1.1 For all heat input evaluation, the cross-weld tension test shall pass if failure location is outside of the weld metal. The ultimate tensile strength at failure shall be reported for information.

If a test fails in the weld metal, two additional tests shall be conducted. If either of these tests fail in the weld metal, a new higher strength test weld shall be completed for evaluation (see X.4.1.6).

X.5.2 CVN Impact Test of HAZ

X.5.2.1 Unless otherwise agreed, the tests shall meet the requirements of 9.8.1 and 9.8.3.

X.5.2.2 If one test (comprising of a set of three test specimens) fails the CVN impact requirement, two additional tests may be tested from the same location. If either of these tests fails, the evaluation configuration (see clauses X.3.3.1 to X.3.3.3) fails the test requirement.

X.5.3 CTOD Test

X.5.3.1 Unless otherwise agreed, the minimum acceptance criterion shall be 0.10 mm (0.0040 in.).

X.5.3.2 If any of the initial valid CTOD tests fails to meet the required acceptance value, three additional tests shall be made.

X.5.3.3 For additional tests made according to X.5.3.2, the following apply:

a) all three additional tests shall meet the required value for the prequalification to be considered acceptable with no further testing, and

b) if there are any failures in the additional tests, the provisions in 7.1.6 and 7.1.7 of BS 7910:2019 may be utilized to address scatter in the results and determine the lower bound of representative fracture toughness.

X.5.4 Hardness Test

NOTE To demonstrate weldability of a material, low hardness may not be the best criterion.

X.5.4.1 General

For sour service applications, unless otherwise agreed, the requirements of H.4.4 also apply.

X.5.4.2 Traverse

Unless otherwise agreed, the macrohardness in the parent metal and HAZ shall be ≤ 350 HV10.

For parent metal tests, individual hardness readings exceeding the applicable acceptance limit may be considered acceptable if the average of a minimum of three and maximum of six additional readings taken within close proximity does not exceed the applicable acceptance limit, and if no such individual reading exceeds the acceptance limit by more than 10 HV10 units.

Retesting on a new specimen machined from the same weld is permitted if agreed.

X.5.4.3 Mapping

The average microhardness difference between the parent metal and the HAZ shall be as agreed. Retesting on a new specimen machined from the same weld is permitted if agreed.

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X.6 Inspection

X.6.1 Specific Inspection

The frequency of inspection for low, moderate and high heat input for each configuration (i.e. combination of WT x grade x delivery condition as defined in X.3.3.1 to X.3.3.3) shall be given in Table X.1. Inspection frequencies for alternate evaluation shall be agreed between purchaser and manufacturer.

Table X.1—Inspection Frequency

Type of Inspection	Frequency of Inspection
Cross weld tension test	Once per test weld
HAZ CVN impact test (X.6.2.2)	Unless otherwise agreed, one set of 3 specimens per test weld at location (1) (see Figure X.2)
HAZ CTOD test (X.6.2.3)	A set of 3 specimens per test weld at location (1) (see Figure X.2)
Hardness traverse test (X.6.2.4.1)	Two tests per test weld
Hardness mapping (X.6.2.4.2)	Two hardness maps per test weld, unless otherwise agreed
Non-destructive inspection (X.7)	Each test weld

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X.6.2 Samples and Test Pieces for Mechanical Tests

X.6.2.1 General

NOTE The overlaps areas (typically 0° and/or 180° positions) shall be avoided for sampling as the Heat Input is not constant and homogeneous in these areas (variation of welding parameters).

X.6.2.1.1 For low, moderate, and high heat input evaluation, the tensile, CVN impact, and hardness tests samples shall be taken, and the corresponding test pieces shall be prepared, in accordance with the applicable reference standard in this specification.

X.6.2.1.2 For alternate evaluation, unless otherwise agreed, such tensile, CVN impact and hardness test samples shall be taken and corresponding test pieces shall be prepared, in accordance with the applicable reference standard in this specification.

X.6.2.1.3 Samples and test pieces for the various types of tests shall be taken according to the supplementary details in 10.2.3.2, 10.2.3.3, and X.6.2.2 to X.6.2.4.

X.6.2.2 CVN Impact Test

X.6.2.2.1 The set of three specimens shall be cut from a welded plate or pipe. The tests shall comply with the validity criteria specified in the relevant test standard.

X.6.2.2.2 The axis of the notch shall be located at mid-thickness at location (1) (coarse grained HAZ – away from the fusion line) of the welded side with 0° bevel as defined in Figure X.2.

X.6.2.2.3 The location of the notch and fracture path may be confirmed by metallography both before and after testing and shall be completely in the HAZ.

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X.6.2.3 CTOD Test

X.6.2.3.1 Test specimens shall be prepared in accordance with ISO 15653 with dimensions of B x 2B or B x B for smaller diameters, where B is equal the thickness of the specimen.

X.6.2.3.2 Test specimens shall be notched and fatigue pre-cracked through-thickness across the CGHAZ region as specified in Figure X.2 (location 1).

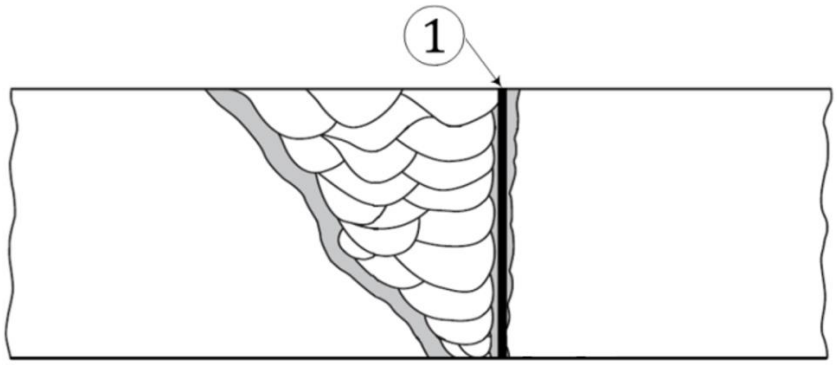
X.6.2.3.3 There shall be at least 3 valid tests in compliance with the validity criteria as specified in the relevant test standard.

X.6.2.3.4 The location of notch and fatigue pre-crack shall be confirmed by metallography both before and after testing to ensure the fracture initiation occurred in the HAZ. Tests where fracture initiation occurs in the weld metal are considered invalid.

For the coarse grain HAZ (CGHAZ) notch, at least 15 % of the central ⅔ of the section thickness should be in CGHAZ or the un-refined HAZ material.

The fusion line shall be considered part of the weld metal but not be included in the determination of % CGHAZ sampled.

NOTE The 15 % of sampled CGHAZ need not be continuous.



Key

[1] In the coarse grain HAZ (CGHAZ) − to be determined by metallography.

Figure X.2— Location of notch for CVN Impact and CTOD test specimen

X.6.2.4 Hardness

X.6.2.4.1 Traverse Test

X.6.2.4.1.1 In plate welding, two specimens shall be cut at the $^{1}/_{3}$ and $^{2}/_{3}$ length of the weld, at least 300 mm (12 in) apart.

X.6.2.4.1.2 For pipe ring welding, two specimens shall be extracted at 180° apart.

X.6.2.4.1.3 For each metallographic cross-sections, a macrohardness survey shall be conducted according to Figure X.3. For wall thickness less than 6 mm (0.236 in) it is necessary to carry out only the inside and outside surface traverses.

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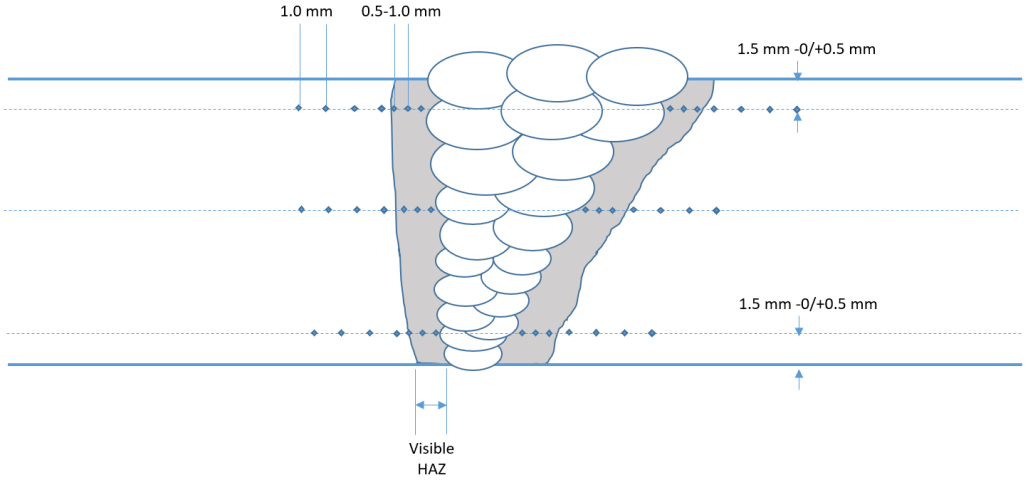


* In the HAZ, indentations shall be made onto material unaffected by adjacent indent along the traverse for each 0.5–1.0 mm (0.020 – 0.040 in) as close as possible according to the hardness standard to ensure indention is made into material unaffected by adjacent indent.

** The first indentation in the HAZ shall be placed as close to the fusion line as possible and with a maximum distance of 0.5 mm (0.020 in) between the centre point of the indentation and the fusion line.

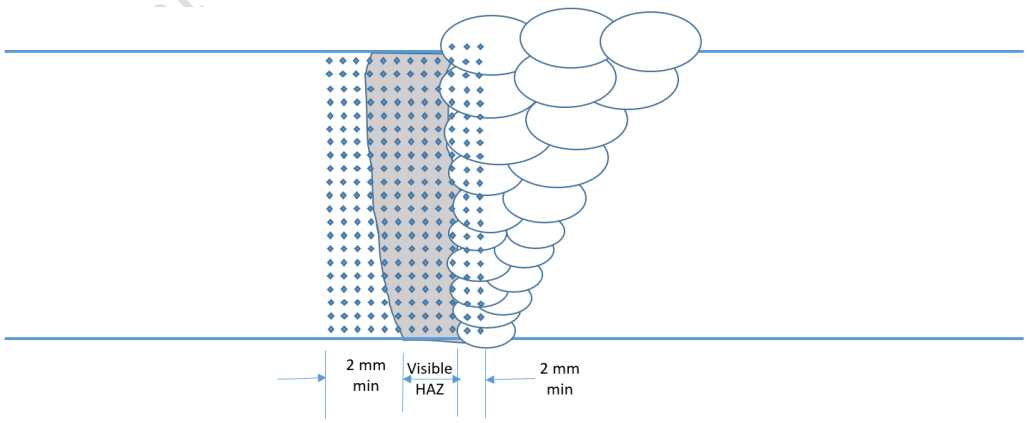
Figure X.3— Location of Hardness Traverse Test

X.6.2.4.2 Mapping Test

X.6.2.4.2.1 For plate welding, two specimens shall be extracted at $^{1}/_{3}$ and $^{2}/_{3}$ length of the weld, at least 300 mm (12 in) apart. For pipe ring welding, two specimens shall be extracted at 180° apart.

X.6.2.4.2.2 A hardness mapping shall be performed on the welded side with 0° bevel through the thickness into at least 2 mm (0.080 in) of the weld metal from the fusion line (weld side), complete visible HAZ, and at least 2 mm (0.080 in) into the base metal permitting the generation of a visual hardness characterization in the HAZ region (Figure X.4).

NOTE Indent spacing of ~0.5mm has been used by some in industry.



* Spacing and number of indentations may not be to scale.

Figure X.4—Hardness Mapping

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X.6.3 Mechanical Test Methods

X.6.3.1 CVN Impact Test

Unless otherwise agreed, the CVN impact test temperature shall be 0 ˚C (+32 ˚F).

X.6.3.2 CTOD Test

X.6.3.2.1 CTOD testing shall be carried out in accordance with, ISO 15653 or ASTM E1820.

X.6.3.2.2 Unless otherwise agreed, test temperature shall be 0 ˚C (+32 ˚F).

NOTE Tests conducted at lower temperature may be used and evaluated to the same criteria at the manufacturer's discretion.

X.6.3.2.3 Sectioning of CTOD samples should be made following testing, to ensure sampling and notching at the required areas.

Pre- and post-testing macrographs shall be supplied to confirm the pre-crack and crack straightness and location at the desired HAZ region.

X.6.3.3 Hardness Test

X.6.3.3.1 Macrohardness testing according to Figure X.3 shall be performed using the Vickers test in accordance with ISO 6507-1 or ASTM E92 with a 10 kg load.

X.6.3.3.2 Microhardness testing according to Figure X.4 shall be performed using the Vickers test in accordance with ISO 6507-1, ASTM E92 or ASTM E384. Unless otherwise agreed, the hardness load shall be 0.5 kg with 0.5mm (0.020 in) spacing.

X.7 Nondestructive Inspection

Each test weld should be inspected by visual, and UT or radiographic testing and the weld area being mechanically tested should satisfy the acceptance criteria of the visual and NDT requirements of this specification (API 5L) or API 1104 prior to being sent for sampling/mechanical testing.

X.8 Reporting

The final report shall include, as a minimum, the following:

a) welding procedure specifications,

   NOTE Including, for example, welding parameters, heat input, pre-heat and inter-pass temperatures, fit-up configurations, etc,

b) welding details,

c) mill certificates of plate or pipe material used, including as a minimum the heat and product analysis,

d) NDT and mechanical test results, including any failures,

e) specified macrographs and micrographs (if any), and

f) interpretation of NDT and mechanical test results (if required).

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