

Procedures for Testing Casing and Tubing Connections

API RECOMMENDED PRACTICE 5C5
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Suggested revisions are invited and should be submitted to the Standards Department, API, 200 Massachusetts Avenue, NW, Suite 1100, Washington, DC 20001, standards@api.org.

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Introduction

This recommended practice (RP) is part of a process to provide reliable threaded tubing and casing connections fit for purpose for the oil and natural gas industry. It has been developed based on improvements to API RP 5C5, Third Edition, with input from leading users, manufacturers, and testing consultants from around the world. This RP represents the knowledge of many years of testing experience.

The validation of the connection test load envelope and failure limit loads is relevant to design of tubing and casing for the oil and natural gas industries. Tubing and casing are subject to loads that include internal pressure, external pressure, axial tension, axial compression, bending, torsion, transverse forces, and temperature changes. The magnitude and combination of these loads result in various pipe body and connection failure modes. Connection failure modes and loads are generally different and often less than that of the pipe. Consequently, experimental validation is recommended when previous testing/analytical information and sufficient field experience are not available to provide confidence in the use of the connection. The user is responsible for appropriate interpretation of the test data and determination of the user's minimum connection performance envelope.

When evaluating a connection performance envelope, it is necessary to consider the possible range of performance parameters and to apply test and limit loads under conditions targeting the extremes of those parameters. Testing at the extremes of the performance parameters assures that the production population that falls within these limits meets or exceeds the performance of the test population. Variables that contribute to threaded connection performance include dimensional tolerances, mechanical properties, surface treatment, makeup torque, and the type and amount of thread compound. For typical proprietary connections, worst-case dimensional tolerances are assumed and defined in this RP. For other connection designs, analysis may be required to define worst-case tolerance combinations.

It is necessary that users of this RP be aware that further or differing requirements might be needed for individual applications. This RP is not intended to inhibit a vendor from offering, or a purchaser from accepting, alternate equipment or engineering solutions for an individual application. This is particularly applicable when there is innovative or developing technology. Where an alternative is offered, it is the responsibility of the vendor to identify any variations from this RP and to provide details.

For specific applications that are not evaluated by the tests herein, supplementary tests may be appropriate. Annex G describes some example of special applications where supplementary testing may be considered. The user and manufacturer should discuss well applications and the potential limitations of the connection under consideration.

Representatives of users and/or other third-party personnel are encouraged to monitor the tests.

Procedures for Testing Casing and Tubing Connections

1 Scope

This Recommended Practice (RP) defines tests to determine the galling tendency, sealing performance, and structural integrity of threaded casing and tubing connections. The words “casing” and “tubing” apply to the service application and not to the diameter of the pipe. This RP addresses the primary loads to which casing and tubing strings are subjected: fluid pressure (internal and/or external), axial force (tension and/or compression), bending (buckling and/or wellbore deviation), and temperature variations.

2 Normative References

The following referenced documents are indispensable for the application of this RP. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

API Specification 5CRA, *Specification for Corrosion-resistant Alloy Seamless Tubes for Use as Casing, Tubing and Coupling Stock*

API Specification 5CT, *Specification for Casing and Tubing*

API Technical Report 5C3, *Technical Report on Equations and Calculations for Casing, Tubing, and Line Pipe Used as Casing or Tubing; and Performance Properties Tables for Casing and Tubing*

API Specification 5L, *Specification for Line Pipe*

ASTM A370 ¹, *Standard Test Methods and Definitions for Mechanical Testing of Steel Products*

3 Terms, Definitions, Symbols, and Abbreviations

3.1 Terms and Definitions

For the purposes of this document, the following definitions apply.

3.1.1

actual API collapse curve at ambient temperature

Derived for the test specimen from API 5C3 using measured maximum average outside diameter (OD), measured minimum average wall, and measured minimum ambient temperature material yield strength as input parameters.

NOTE For the reference to API 5C3, the appropriate section that applies addresses the *external pressure resistance*.

3.1.2

actual VME curve at ambient temperature

Derived for the test specimen from API 5C3 using measured maximum average OD, measured minimum wall (for hoop stress only), measured minimum average wall, and measured minimum ambient temperature material yield strength as input parameters.

NOTE For the reference to API 5C3, the appropriate section that applies addresses the *triaxial yield of pipe body*.

3.1.3

ambient temperature

Actual current temperature of the test lab environment at the time of testing.

¹ ASTM International, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania 19428, www.astm.org.

3.1.4**axial-pressure load diagram**

Plot of pressure versus axial load showing pipe body reference envelope, connection evaluation envelope (CEE), and test load envelope (TLE) or limit load extremes.

3.1.5**bi-axial scaling**

The scaling of an original envelope or curve along both the axial load axis and the pressure load axis with the appropriate scaling factor, thus creating a second envelope or curve that is radially proportional to the original.

3.1.6**connection**

One pin (male end) and its adjoining coupling side or integral box (female end).

3.1.7**connection evaluation envelope****CEE**

Diagram containing the extents to which a connection shall be evaluated.

3.1.8**elevated temperature envelope or curve**

Bi-axially scaled from the corresponding ambient temperature envelope or curve in both the axial load direction and the pressure load direction with the scaling factor being the ratio between the elevated temperature material yield strength and the ambient temperature material yield strength.

3.1.9**failure load**

Load at which the pipe body or connection will fail as in axial separation, rupture, large permanent deformation (e.g. buckling or collapse), or loss of sealing integrity.

3.1.10**galling**

Form of surface damage resulting from cold welding of contacting material surfaces followed by tearing of the metal during further sliding or rotation.

NOTE There are several degrees of galling used for repair and reporting purposes as defined in 8.2.

3.1.11**interference**

Amount of geometric overlap of mating members created by the design and tolerances of the members.

3.1.12**leak****leakage**

Passage of test medium outside of the containment space whether in the equipment or the connection.

3.1.13**leak tube displacement**

Change in the graduated cylinder water level indicating a volume change due to changes in applied load, temperature, pressure, or a leak.

3.1.14**light galling**

Galling that can be repaired by the use of abrasive paper in accordance with the manufacturer's field service procedures.

3.1.15**limit load**

Load combination extreme (axial load and/or pressure) that defines the failure conditions for the connection, or load combination resulting in large permanent deformation (such as buckling) prior to catastrophic failure.

3.1.16**lot**

Lengths of pipe with the same specified dimensions and grade from the same heat of steel that are heat-treated as part of a continuous operation (or batch).

3.1.17**material test coupon****MT**

Cylinder of material from the pipe and/or coupling stock from which tensile test specimens are cut.

3.1.18**metal-to-metal seal**

Seal or sealing system that relies on high contact stress of mating metal surfaces to achieve a seal.

NOTE The thread compound and surface treatment can affect, either beneficially or detrimentally, the performance of a metal seal.

3.1.19**moderate galling**

Galling that can be repaired by the use of fine files and abrasive paper in accordance with the manufacturer's field service procedures.

3.1.20**mother joint**

Length of pipe or coupling stock from which short lengths are cut for machining connection test specimens.

3.1.21**multiple seals**

Sealing system having more than one independent barrier, with each barrier forming a seal.

3.1.22**nominal API collapse curve at ambient temperature**

Performance curve derived for the test specimen from API 5C3 using API specified OD, API specified wall, and API specified minimum material yield strength as input parameters.

NOTE For the reference to API 5C3, the appropriate section that applies addresses the *external pressure resistance*.

3.1.23**nominal VME curve at ambient temperature**

Performance curve derived for the test specimen from API 5C3 using API specified OD, API specified wall, k_{wall} (for minimum wall), and API specified minimum material yield strength as input parameters.

NOTE For the reference to API 5C3, the appropriate section that applies addresses the *triaxial yield of pipe body*.

3.1.24**pipe body reference envelope**

Diagram containing the extremes of pipe body performance based on measured material properties and geometries.

NOTE Pipe body performance is also known as VME yield; see API 5C3 for collapse.

3.1.25**proprietary high collapse curve at ambient temperature**

Uni-axially scaled from the ambient temperature nominal API collapse curve in the pressure direction only with the scaling factor being the ratio between the uni-axial proprietary collapse pressure and the uni-axial nominal API collapse pressure.

3.1.26**pup joint or pup**

Short pipe length usually with threaded ends.

3.1.27**QI-QIII cycles**

Load cycling between QI (tension and internal pressure) at ≤ 150 °F (65 °C) and QIII (compression and external pressure) at 356 °F (180 °C).

3.1.28**resilient seal**

Seal or sealing system that relies on entrapment of a seal ring within a machined groove in the connection (e.g. in the thread-form or on a seal area) to achieve a seal.

3.1.29**seal**

Pressure barrier to prevent the passage of the test medium.

3.1.30**seal ovality**

Maximum seal diameter minus the minimum seal diameter divided by the average seal diameter multiplied by 100.

3.1.31**severe galling**

Galling that cannot be repaired by the use of fine files and abrasive paper in accordance with the manufacturer's field service procedures.

3.1.32**single seal**

One pressure barrier or multiple pressure barriers that cannot be physically differentiated in their function.

3.1.33**specimen**

Two pups, each with a pin connection and a shared coupling forming a coupled assembly, or two pups, one with a pin connection and one with a box connection forming an integral assembly.

3.1.34**tensile test specimen**

Full-body wall strip or round specimen taken from a material test coupon (MT).

3.1.35**test load envelope****TLE**

Test load points (axial, pressure, bending) in the four quadrants derived from the CEE.

3.1.36**thread lot**

All products manufactured on a given machine during a continuous production cycle that is not interrupted by a tool failure or machine malfunction (excluding worn tools or minor tool breakage), tool holder change (except rough boring bar), or any other malfunction of either threading equipment or inspection gauges.

3.1.37**thread seal**

Seal or sealing system, which relies on intimate fitting of the thread form and usually entrapment of the thread compound within the thread form to achieve a seal.

3.1.38**uni-axial scaling**

The scaling of an original envelope or curve along the pressure load axis only with the appropriate scaling factor, thus creating a second envelope or curve that has the largest separation on the pressure load axis and converges with the original at the same point on the axial load axis.

3.1.39**VME stress**

Equivalent stress based on the von Mises-Hencky maximum distortion energy criterion.

3.2 Abbreviations

For the purposes of this document, the following abbreviations apply.

A	connection A, mill end
AMYS	actual minimum yield strength
B	connection B, field end
BO	breakout
CAL	connection assessment level
CCW	counter-clockwise direction around the test load envelope
CEE	connection evaluation envelope
CEPL	capped end pressure load (tension) at the designated pressure
CRA	corrosion-resistant alloy
CW	clockwise direction around the test load envelope
EP	external pressure
FEA	finite element analysis
FMU	final makeup specimen condition
H	maximum (high) thread or seal interference range
H/H	maximum specified amount of thread compound/maximum specified torque value, and in Figures 4 through 7, maximum thread interference/maximum seal interference
H/L	maximum specified amount of thread compound/minimum specified torque value, and in Figures 4 through 7, maximum thread interference/minimum seal interference
IJ	integral joint
IP	internal pressure
L	minimum (low) thread or seal interference range
L/H	minimum specified amount of thread compound/maximum specified torque value, and in Figures 4 through 7, minimum thread interference/maximum seal interference
LL	limit load

LL1	limit load test path 1
LL2	limit load test path 2
LL3	limit load test path 3
LL4	limit load test path 4
LL5	limit load test path 5
LP	load point
MBG	makeup/breakout galling test
MC	mechanical cycle
MT	material test coupon
MU	makeup
OCTG	oil country tubular goods
OD	outside diameter
PBVME	pipe body von Mises envelope
PF-BS	pin fast taper–box slow taper
PS-BF	pin slow taper–box fast taper
PTFE	polytetrafluoroethylene
SMYS	specified minimum yield strength
TC	thermal cycle
T&C	threaded and coupled
TLE	test load envelope
TS-A	test series A
TS-B	test series B
TS-C	test series C
VME	von Mises equivalent stress
XH	extreme maximum (high) thread or seal interference range
XL	extreme minimum (low) thread or seal interference range

3.3 Symbols

For the purposes of this document, the following symbols apply.

A^a	cycles in TS-A at ambient temperature using gas for internal pressure and liquid for external pressure; for CAL I, liquid may be used for internal pressure
A^e	cycles in TS-A at 356 °F (180 °C) for CAL III and CAL IV using gas for internal pressure and an appropriate liquid for external pressure
A_p	nominal or average pipe body cross-section area; based on D and d for nominal, D_{avg} and d_{avg} for average

B^a	cycles in TS-B, without bending, at ambient temperature using gas for CAL II through CAL IV; for CAL I, liquid may be used for internal pressure
B^a_b	cycles in TS-B, with bending, at ambient temperature using gas for CAL II through CAL IV; for CAL I, liquid may be used for internal pressure
B^e_b	cycles in TS-B, with bending, using gas at 356 °F (180 °C) for CAL III and CAL IV, or at 275 °F (135 °C) for CAL II
C	compressive axial force
CEE^a_c	connection evaluation envelope compression at zero pressure at ambient temperature
CEE^a_t	connection evaluation envelope tension at zero pressure at ambient temperature
D	API specified (nominal for non-API pipe) pipe OD
D_{avg}	maximum of average ODs of test specimen pipe body based on measured dimensions at specified planes
D_i	inside diameter
D_{leg}	effective dogleg severity expressed in degrees per 100 ft or degrees per 30 m
D_o	outside diameter
d	nominal inside diameter of pipe body; based on D and t
d_{avg}	average inside diameter of test specimen pipe body based on measurements; based on D_{avg} and t_{avg}
d_{wall}	maximum inside diameter of nominal pipe body or test specimen pipe body; based on D and t_{min} for nominal pipe body and D_{avg} and t_{min} for test specimen pipe body
E_r	error in load frame calibration
E_{rp}	error in load frame calibration expressed in percent
F_{CEPL}	capped-end pressure load acting on the connection
F_a	total axial force, tension or compression (sum of applied loads: F_b , F_i , F_{CEPL})
F_b	bending equivalent axial force
F_c	pipe body reference envelope compression load at 0 pressure (uni-axial compression)
F_f	load frame axial force, tension or compression
F_i	indicated load frame axial force, tension or compression
F_t	pipe body reference envelope tension load at 0 pressure (uni-axial tension)
f_{ymn}	specified minimum material yield strength
I	moment of inertia
I_{max}	maximum design interference between thread or seal members, resulting from pin and box diameter specification and tolerances

I_{min}	minimum design interference between thread or seal members, resulting from pin and box diameter specification and tolerances
I_{range}	range of design interference between thread or seal members, equal to $I_{max} - I_{min}$
K_{hc}	scaling factor for proprietary high collapse pipe
K_{temp}	scaling factor for elevated temperature yield strength
k_{wall}	factor to account for the specified manufacturing tolerance of the pipe wall (e.g. for a tolerance of -12.5% , $k_{wall} = 0.875$)
L_A	length of pin A end from coupling face (or connection) to end cap or grip
L_B	length of pin B end from coupling face (or connection) to end cap or grip
L_C	length of coupling or connection if integral
L_D	length from face of integral box to Section 5 measurement plane on pup joint A
L_{MA}	length between Sections 1 and 5 measurement planes on pup joint A
L_{MB}	length between Sections 1 and 5 measurement planes on pup joint B
L_{pj}	minimum unsupported pup joint length
P_d	pipe body reference envelope pressure at 0 axial load (uni-axial internal pressure)
p_c	API collapse rating for specified OD, specified wall thickness, and specified minimum yield strength (see API 5C3)
	NOTE For the reference to API 5C3, the appropriate section that applies addresses the <i>external pressure resistance</i> .
p_i	internal pressure
p_{ib}	internal pressure with bending
p_o	external pressure
q_{ac}	actual leak rate to be reported
q_o	observed leak rate
R	radius of curvature of the pipe body at the axis of the pipe
T	tension axial force
t	API specified (nominal for non-API pipe) wall thickness of pipe body
t_{avg}	average wall thickness of test specimen pipe body based on measurements
t_{min}	minimum wall thickness of pipe body
η_{lds}	leak detection system efficiency
σ	stress
σ_a	axial stress without bending

σ_{ab}	axial stress with bending
σ_b	axial stress due to bending
σ_c	axial compressive yield strength, if available; otherwise, use axial tensile yield strength
σ_e	equivalent stress
σ_h	hoop (tangential) stress
σ_{ho}	hoop (tangential) stress at OD
σ_r	radial (normal) stress
σ_{ro}	radial (normal) stress at OD
σ_t	transverse tensile yield strength if available, otherwise use axial tensile yield strength
σ_{tc}	defined transverse compressive yield strength if available; otherwise use axial tensile yield strength
σ_y	axial tensile yield strength

4 General Requirements

4.1 General Information

This RP consists of the following major parts.

- Sections 4 through 8 outline the requirements and procedures to conduct tests on connections based on connection data supplied by the manufacturer.
- Annex A lists the requirements for the manufacturer's connection specification sheet and test specimen datasheets.
- Annex B includes the forms required to present the data collected during the tests.
- Annex C lists the information required to be provided in the full test report (also refer to Section 9).
- Annex D provides a methodology for calculating and examples of pipe body reference envelopes, the TLE, and the test load points.
- Annex E gives an example of a load frame calibration.
- Annex F provides considerations for connection product-line evaluation.
- Annex G provides guidelines for supplemental tests that can be used for special applications.

4.2 Connection Testing Flow Chart

The connection testing flow chart depicts in a series of figures the critical path for each specimen in determining how it shall be tested. Specimen characterization (Figure 1), pipe body reference envelope and CEE (Figure 2), and TLEs and test load schedules (Figure 3) are developed individually for each test specimen. Refer to 5.5 for material characterization. Refer to 7.3 for pipe body reference envelope, CEE, TLE, and test load schedule determination.

NOTE This section assumes that the coupling or box is not the weaker member of the connection assembly.

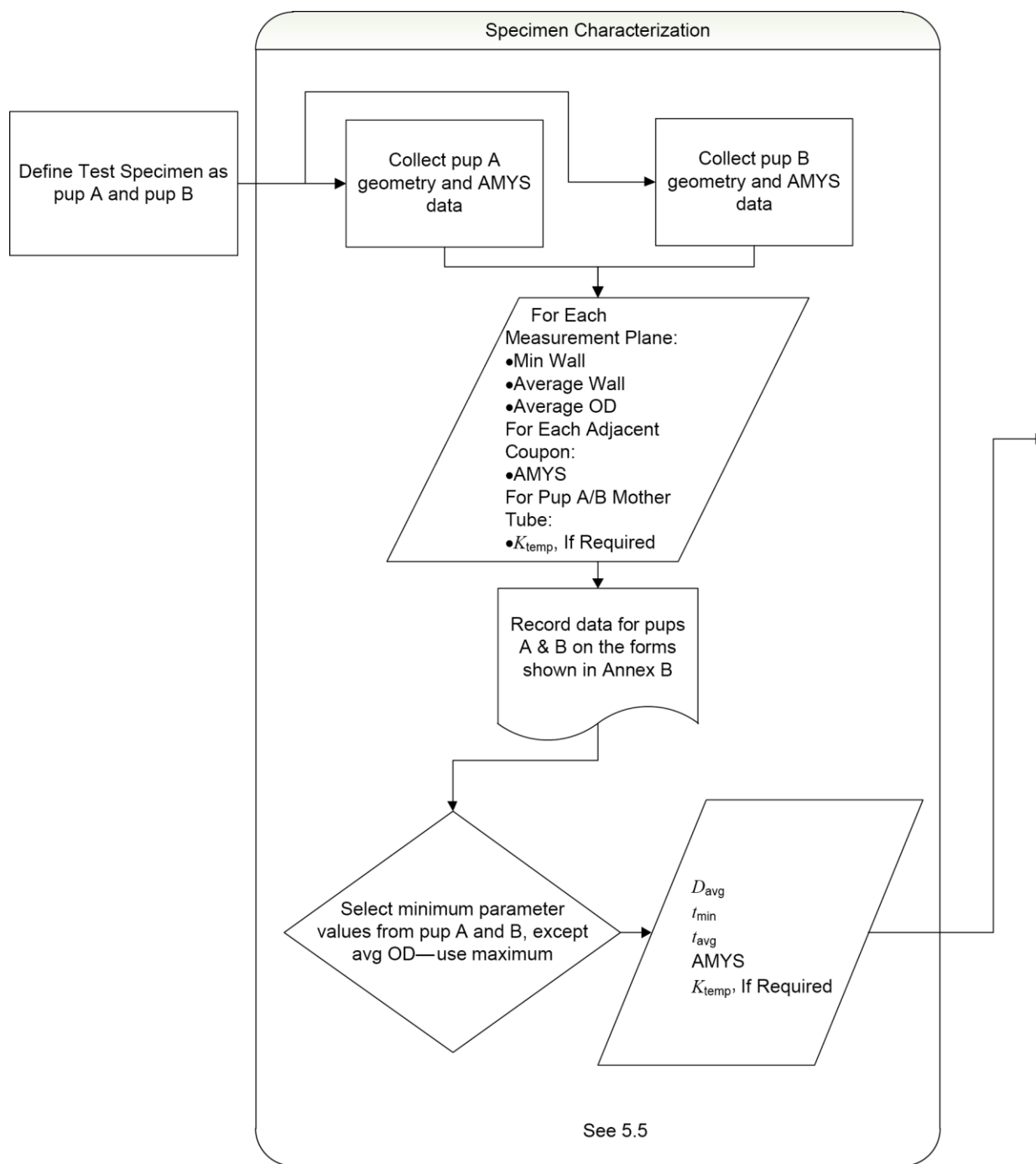


Figure 1—Flow Chart for Determining Input Parameters Used to Construct Pipe Body Reference Envelope for a Test Specimen

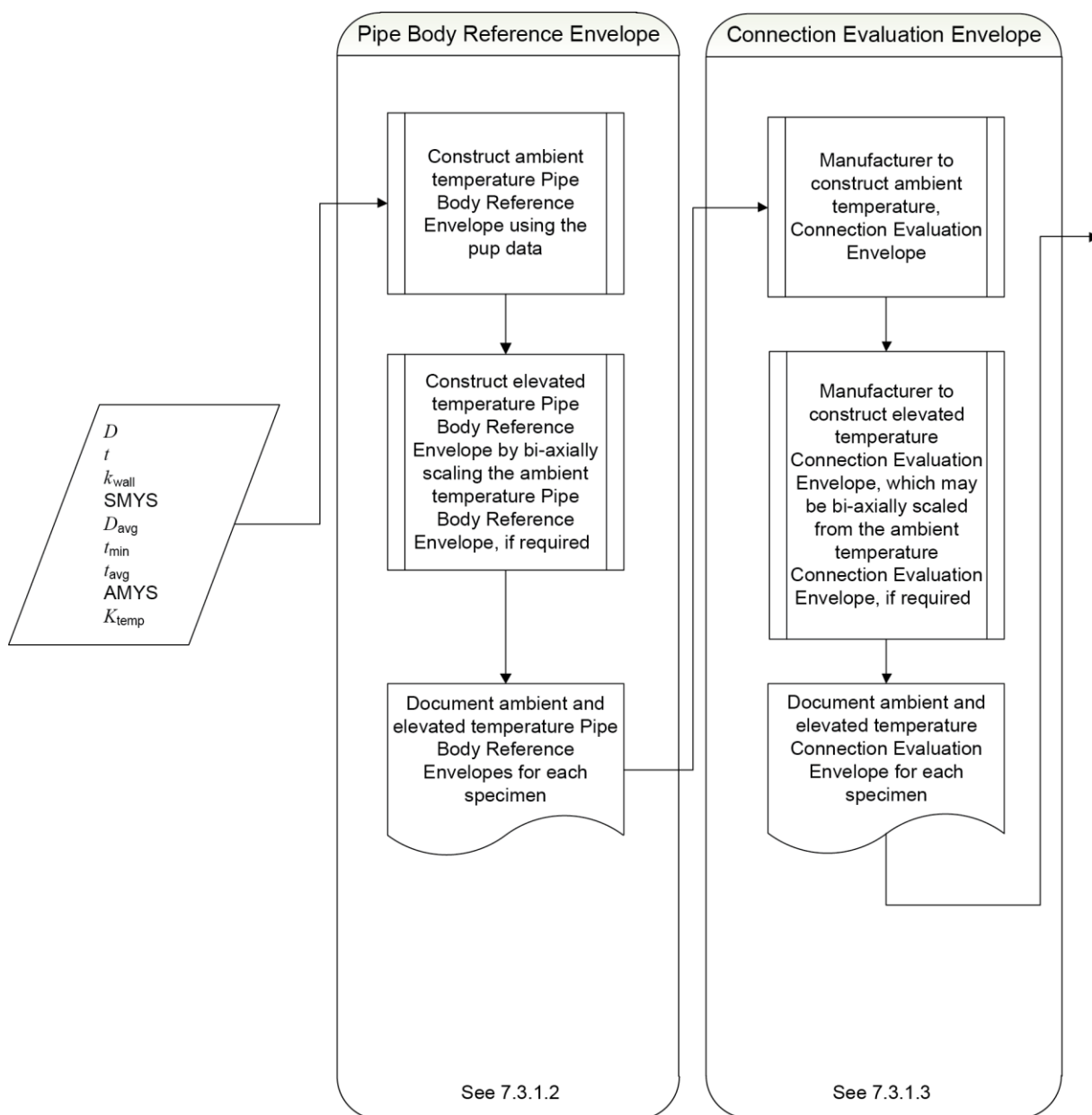


Figure 2—Flow Chart for Determining Ambient and Elevated Temperature Pipe Body Reference Envelope and Connection Evaluation Envelope for a Test Specimen

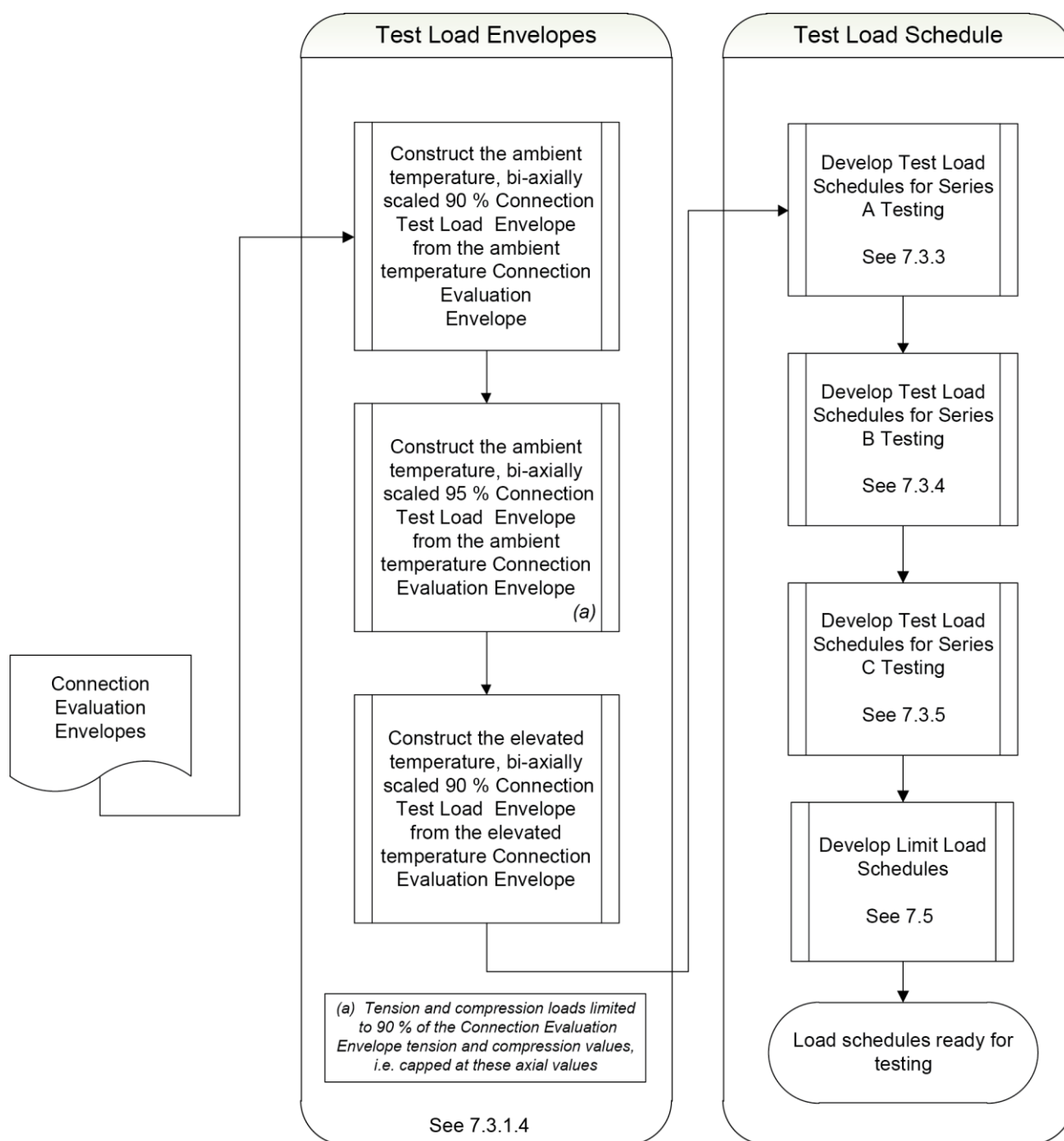


Figure 3—Flow Chart for Determining Ambient and Elevated Temperature Test Load Envelopes and Test Load Schedules for a Test Specimen

4.3 Connection Specification Sheet and Test Specimen Datasheet

Prior to beginning a test, the manufacturer shall provide a test plan. The test plan shall contain a connection specification sheet stating the intended assessment level to which test is performed, its geometry, and a connection datasheet stating the claimed minimum performance properties in terms of tension, compression, internal pressure, external pressure, bending, and torque based on minimum API pipe body performance properties for specified minimum material yield strength, specified OD, specified wall, and minimum wall (see Table A.1 for the connection specification sheet). The manufacturer shall provide a drawing representative of the cross-sectional area of the connection and documentation detailing the specifications, processes, and procedures required for the complete manufacture and inspection of the connection. The manufacturer shall provide the connection makeup parameters and repair procedures. Additionally, the manufacturer shall

identify any specific pipe body attributes (examples include 90 % minimum specified wall, high collapse, or controlled yield strength) that are required for the connection being evaluated.

For each test specimen, the manufacturer shall provide a test specimen datasheet. For each test specimen, the manufacturer shall provide the following plots in two-dimensional graphical form for both ambient and elevated temperature testing.

- a) Pipe body reference envelope (VME plot with appropriate collapse curves).
- b) CEE (polygon or other form, presented on same axes and scale as the pipe body reference envelope).
- c) TLE.

The manufacturer's method of calculation should be used to derive the CEE. The CEE shall include the required CEE points specified in Table 7. Performance data may be used to determine the CEE. The TLE shall be bi-axially scaled as a percentage (80 %, 90 %, 95 %, or 100 %, whichever applies) of the CEE, shall include the required load points specified in Table 7, and shall be used to calculate the test load schedules.

The manufacturer should define as completely as possible the limit loads for each test specimen (see 7.4 and 7.5).

In the calculation of both the pipe body reference envelope and CEE, it is the intent of this RP to test each specimen to as high a load or combination of loads as safely practical.

4.4 Quality Control

Quality control procedures for the manufacturing of test specimens shall be documented and be consistent with procedures used for connections manufactured for well service. The connection manufacturer shall ensure that the connections manufactured for the purpose of these design validation tests are of the same design and manufactured to the same dimensions and extremes of tolerances (see 6.5) as those supplied for well service. The connection manufacturer shall issue a declaration of conformity. The manufacturer shall provide the process control plan, which shall include the product drawing number(s) and associated revision level(s) as well as the procedure number and the associated revision levels for applicable sub-tier documents, e.g. manufacturing, gauge calibration, gauging procedure, surface treatment (type and/or thickness), thread compound (type and quantity, or other amount indicators), and makeup procedures. These procedures and any others determined necessary to provide a consistent product for well service shall be used during manufacturing of test specimens (see A.1.6).

4.5 Test Facility Safety

The test guidelines in this RP may include loads approaching the actual yield envelope for the test specimen. Testing may result in failure of the test specimen or equipment. For safety reasons, the following shall be taken into consideration.

- a) Filler bar.
 - 1) Test specimens subjected to internal pressure should include filler bars to reduce the volume of compressed pressurizing media, thereby reducing the energy that would be released in the event of a catastrophic failure.
 - 2) Filler bars should be non-permeable to the pressurizing media (gas or liquid) and shall not trap or retain pressurized media. The filler bar should be dimensioned to reduce the internal specimen volume substantially, but shall not result in any mechanical interference with the specimen when the specimen deforms during test execution.
 - 3) Filler bars located within the connection of the test specimen shall be radially positioned in such a way that there is minimal contact with the connection inner diameter (D_i). Filler bars should extend (without contacting the connection inner diameter) at least one-half the pipe diameter beyond the

face of the box and the end of the pin for an integral connection or beyond the face of both ends of the coupling for a coupled connection, and centered over the length of the connection.

b) Specimen containment.

- 1) Load frames and pressure vessels should have sufficient barriers to contain ejected material, high-pressure liquids, or high-pressure gasses resulting from testing or failure of the test specimen.
- 2) For elevated temperature external pressure testing, leak detection shall be a closed system that prevents hot fluid from escaping in an unsafe manner.
- 3) Testing in quadrants II and III potentially have high compressive loading, which may result in load frame damage. Anti-buckling equipment is recommended.

c) Test media.

- 1) When testing at elevated temperatures, non-flammable materials, fluids with flash points in excess of the test temperature extremes, and heat-resistant materials should be used to minimize fire potential.
- 2) During limit load testing, the test media shall be liquid.

d) Fire safety.

The test facility shall have a safety procedure in place which covers actions to take in the event of a fire in the test area.

5 General Test Requirements

5.1 Test Principle

5.1.1 Overview

Connection performance data are generated by testing. Four test programs, known as connection assessment levels (CALs) are presented. The increasingly arduous test programs are developed to provide means to assess connection performance. These test programs increase in rigor by increasing the number of test parameters and test specimens.

Users of this RP should be aware that the recommendation to apply test loads in each of the four quadrants (QI, QII, QIII, and QIV) may result in load-path-dependent connection behavior. The four quadrant testing approach presented herein is intended to make the testing program more efficient; however, the program may not reflect the loading on any individual connection. This is due to the practical fact that no connection used in a casing or tubing string will experience the high loads associated with service at both the top and bottom of the string. Testing programs that apply realistic load combinations accounting for service separately at the top or bottom of the strings can provide more representative connection performance test outcomes in cases where the connections are influenced by this load path dependency. As a result of these and other considerations, it is important that users of this RP apply appropriate engineering judgement in the development and application of these test procedures and in the interpretation of test outcomes.

The test programs do not include all possible service scenarios. For example, the presence of a corrosive fluid that may influence the service performance of a connection is not considered and is beyond the scope of this RP.

Users of this RP shall specify the CAL required based on the needs for the particular service intended. Users of the connection should be familiar with the defined connection test rigor, the performance limits, and limit loads. The CALs are defined as follows.

a) *CAL IV (5 Specimens)—Most Testing Rigor.*

CAL IV is the most rigorous test plan. CAL IV test matrix exposes the connection to repeated path-dependent test loads including internal pressure, external pressure, tension, compression, and bending at

ambient and elevated temperature. The total cumulative hold time is approximately 238 hours. CAL IV test conditions subject the connection to extensive thermal loading at an elevated temperature of 356 °F (180 °C). Limit load tests are performed to failure in quadrants I, II, and III of the axial/pressure load diagram.

b) Connection Assessment Level III (Five Specimens)—Significant Testing Rigor.

CAL III is a significantly rigorous test plan. As with CAL IV, CAL III test matrix exposes the connection to repeated, path-dependent test loads including internal pressure, external pressure, tension, compression, and bending at ambient and elevated temperature. CAL III test conditions subject connections to less severe thermal cycling levels than CAL IV. The total cumulative hold time is approximately 185 hours. Elevated temperature requirements are maintained at 356 °F (180 °C). Limit load tests are performed to failure in quadrants I, II, and III of the axial/pressure load diagram.

c) Connection Assessment Level II (Three Specimens)—Moderate Testing Rigor.

CAL II is a moderate rigor test plan. The CAL II test matrix exposes the connection to repeated, path-dependent test loads including internal pressure, tension, compression, and bending at ambient and elevated temperature. External pressure is evaluated only at ambient temperature and has a reduced number of cycles. Internal pressure testing temperatures are limited to 275 °F (135 °C). Limit load tests are performed to failure in quadrants I and III of the axial-pressure load diagram. The total cumulative hold time is approximately 80 hours.

d) Connection Assessment Level I (Two Specimens)—Less Testing Rigor.

CAL I is a reduced rigor test plan that may utilize liquid or gas as an internal pressurization medium. Testing is conducted at ambient temperature with one test specimen exposed to internal pressure testing under tension and compression loading and bending. External pressure is evaluated at ambient temperature and has a reduced number of cycles. Limit load testing is performed to failure in quadrant I of the axial/pressure load diagram. The total cumulative hold time is approximately 20 hours.

5.1.2 Previous Tests

The testing required by this edition of API 5C5 is more rigorous than for prior editions of API 5C5 for each CAL. Connections previously tested to prior versions of this RP shall retain the CAL test class and edition to which they were successfully tested. The test protocol used and the date of the test protocol used shall be stated in the test report. See Annex C for reporting format. Connection test data obtained from tests performed prior to the establishment of this RP may also be used as part of a design verification process or application test sequence.

5.1.3 Alternative Tests and Deviations

Alternative testing programs may also be performed. The alternative testing program may be chosen for alignment with users' design methodologies, desire to probe additional features and performance of a connection, or to only probe performance up to a limit as required for a specific application (often known as testing to "project loads"). The alternative testing programs may use large portions of this RP as the basis or may differ substantially. Alternative testing programs may be as appropriate as the test protocols in this RP for judging a connection's suitability for use. However, alternative test programs should not be referred to as being tested in accordance with this RP even when they use a portion of this protocol as their basis.

Some of the tests herein, rather than the complete test program, may be adequate to verify suitability for specific applications when experience and related test data are available, for example, on other sizes, weights, and grades. Deviations to the tests specified herein are acceptable and can be referred to as being tested in accordance with this RP (as modified), provided:

- a) the planned deviations are documented in advance,
- b) there is agreement between the parties involved, and

c) the deviations (planned and unplanned) are identified in the full test report.

A discussion of product line evaluation and use of interpolation and extrapolation considerations is provided in Annex F. Note that Annex F is informative only and the information and data presented there are only examples and not intended to be prescriptive recommendations. More stringent acceptance requirements, sensitivity requirements, and/or more extended informative data may be agreed by the user and manufacturer.

5.2 Test Matrix

Table 1 shows a matrix relating the CAL to the relevant total number of test specimens, their identification numbers and the relevant tests. Figures 4 through 7 are a summary of each CAL test program and should be read and followed from the top down.

Table 1—Test Matrix—Sealability Test Series and Specimen Identification Numbers

Connection Assessment Level	Series A 4 Quadrants with Mechanical Cycles (see 7.3.3)	Series A QI-QIII Cycles (see 7.3.3)	Series B 2 Quadrants with Mechanical Cycles (see 7.3.4)	Series C Thermal Cycling Thermal/Pressure and Tension Cycling (see 7.3.5)	Bake-out and Elevated Temperature Tests	Internal Test Pressure Medium (external is liquid)
IV	At ambient and 356 °F (180 °C)	QI at ≤150 °F (65 °C) QIII at 356 °F (180 °C)	Bending required at ambient and 356 °F (180 °C)	10 thermal cycles with pressure/tension 5 mechanical cycles at ≤95 °F (35 °C)	Bake-out @ 356 °F (180 °C)	Gas
Total number of sealability specimens 4	Specimens 1, 2, 3, 4	Specimens 1, 2, 3, 4	Specimens 1, 2, 3, 4	Specimens 1, 2, 3, 4	Test @ 356 °F (180 °C)	
III	At ambient and 356 °F (180 °C)	Not applicable	Bending required at ambient and 356 °F (180 °C)	10 thermal cycles with pressure/tension 5 mechanical cycles at ≤95 °F (35 °C)	Bake-out @ 356 °F (180 °C)	Gas
Total number of sealability specimens 4	Specimens 1, 4		Specimens 1, 2, 3, 4	Specimens 1, 4	Test @ 356 °F (180 °C)	
II	At ambient (reduced cycles)	Not applicable	Bending required at ambient and 275 °F (135 °C)	Not applicable	Bake-out @ 275 °F (135 °C)	Gas
Total number of sealability specimens 2	Specimen 1		Specimens 1, 4		Test @ 275 °F (135 °C)	
I	At ambient (reduced cycles)	Not applicable	Bending required at ambient temperature	Not applicable	Bake-out @ 275 °F (135 °C) Bake-out only	Gas or liquid
Total number of sealability specimens 1	Specimen 1		Specimen 1			

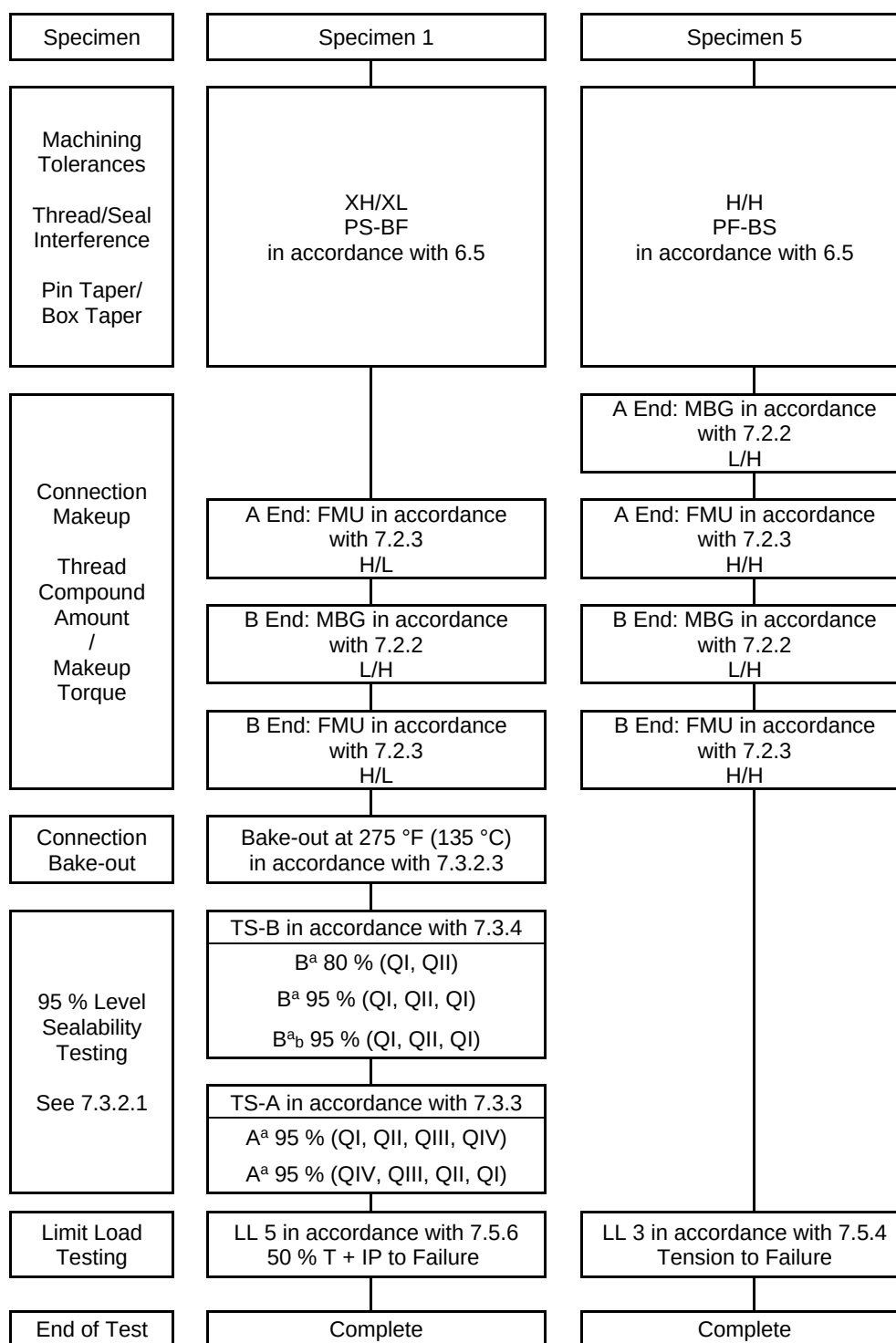


Figure 4—CAL I Test Requirements and Sequence

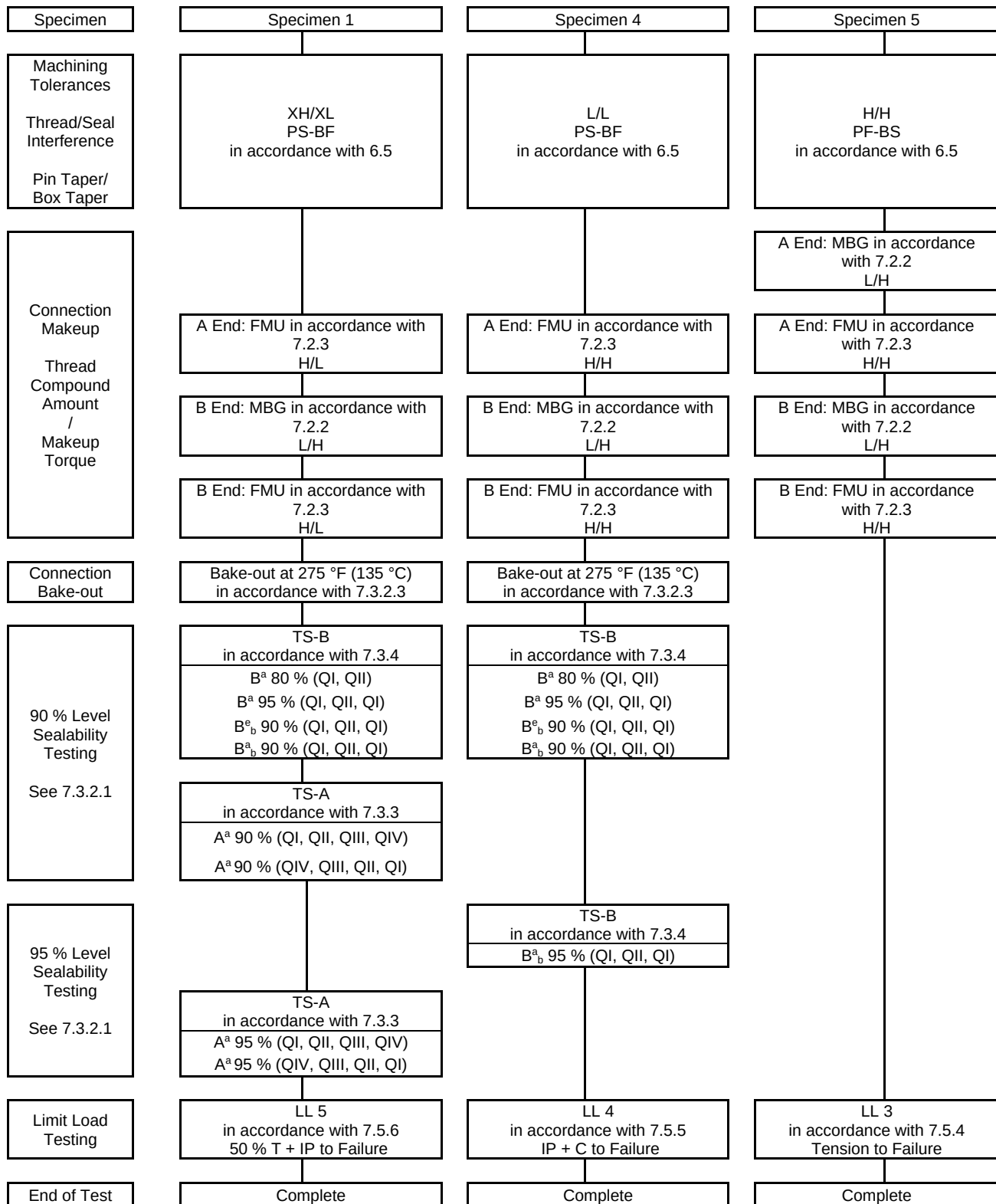


Figure 5—CAL II Test Requirements and Sequence

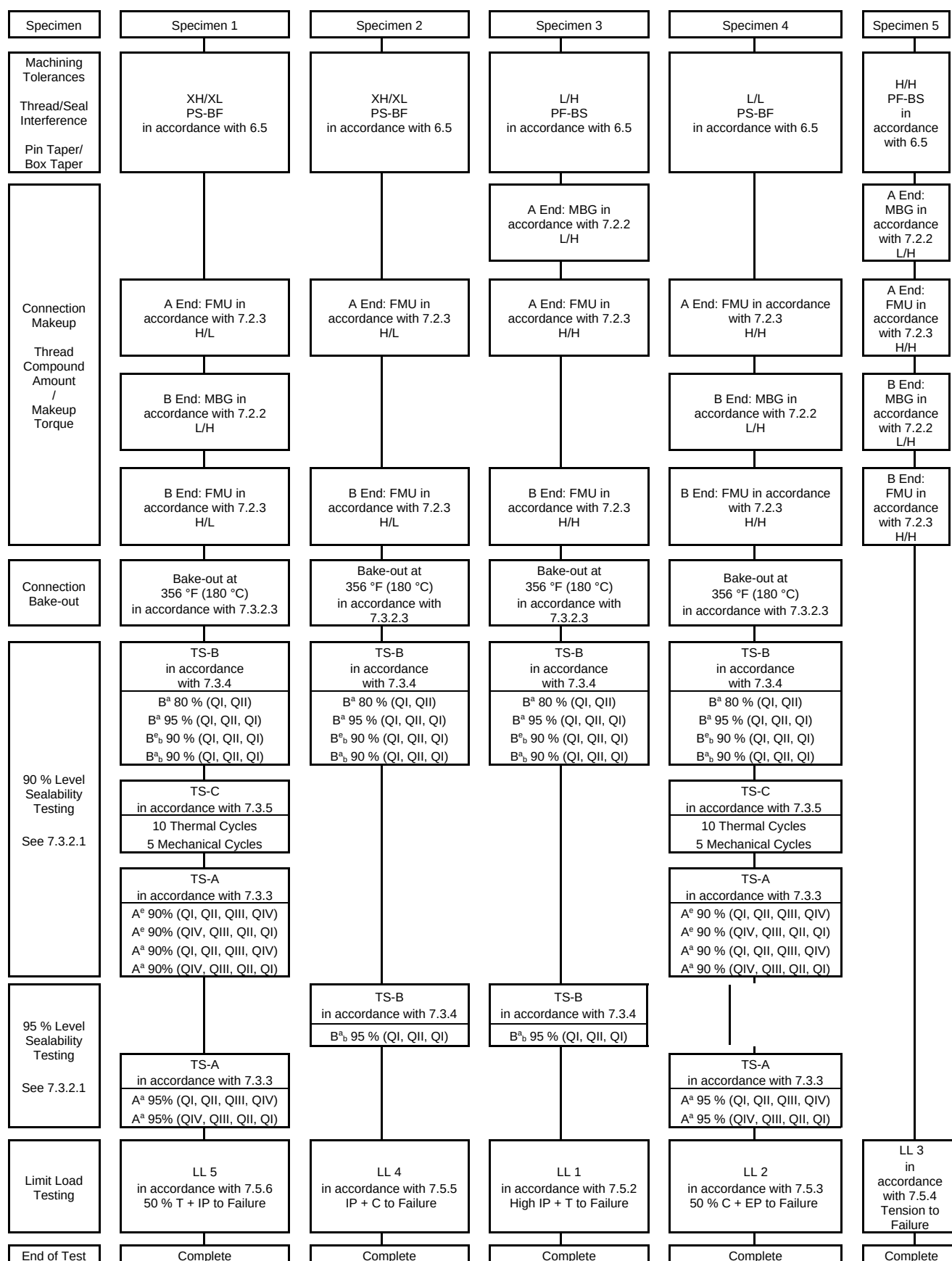


Figure 6—CAL III Test Requirements and Sequence

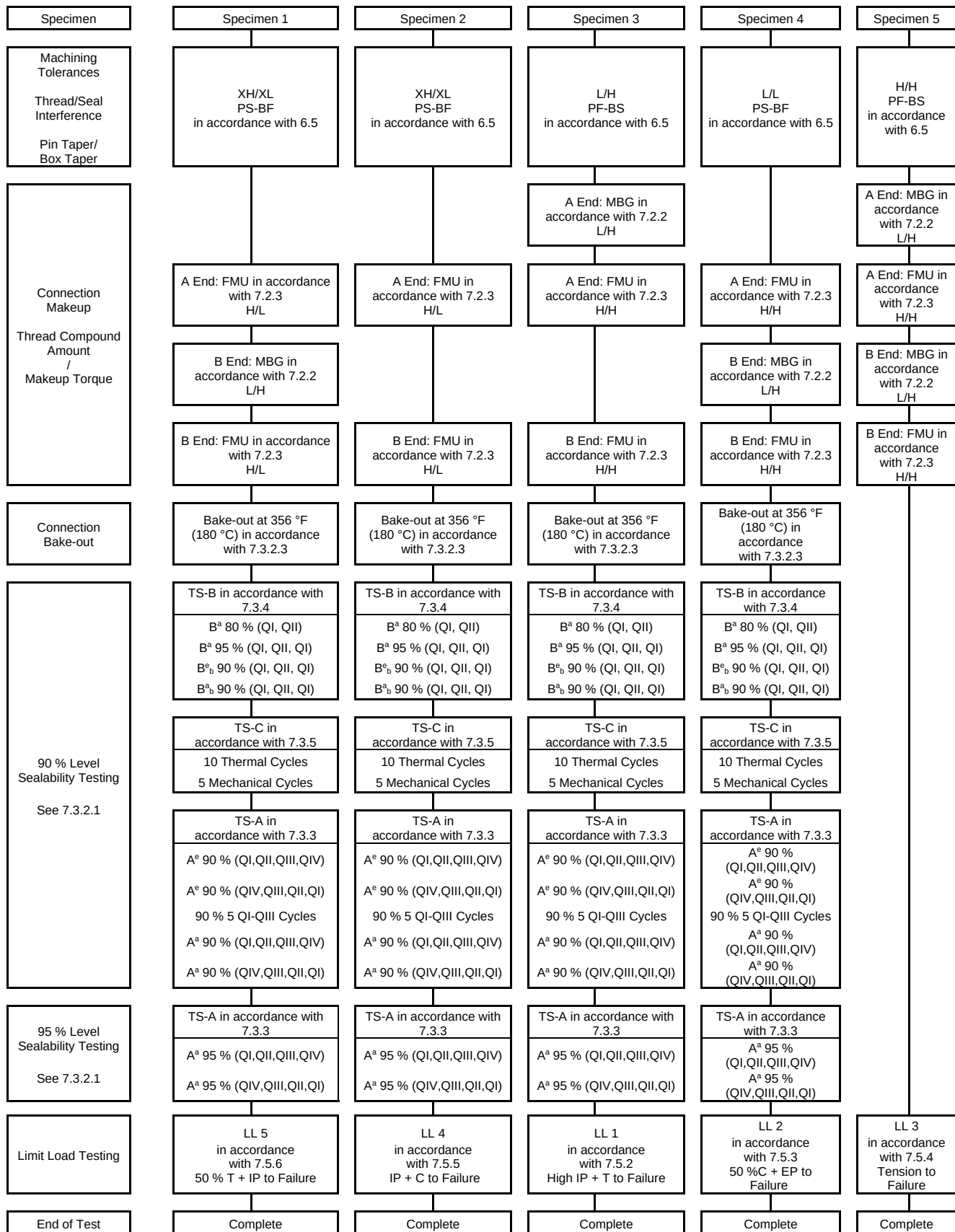


Figure 7—CAL IV Test Requirements and Sequence

5.3 Test Program

5.3.1 Full-scale Testing

Conduct a full-scale test program of makeup/breakout tests, TLE tests, and limit load tests in accordance with the procedures stated in this RP.

Instructions in this RP shall be followed. If adverse conditions not specifically addressed in this RP are encountered, deviations from this RP shall be documented in the test report. In addition, statements should be provided to justify why the modified tests as a result of the deviations should be considered adequate.

5.3.2 Evaluation of Test Results

5.3.2.1 General

Evaluate the results of the physical test program in accordance with Section 8 following the procedure given in 5.3.2.

5.3.2.2 Test Results that Conform to Stated Connection Assessment Level

Completing the tests according to the requirements of this RP for make/break tests, the TLE tests, and the limit load tests, the connection in the size, mass (label: weight), and grade of material [i.e. same specified minimum yield strength (SMYS) and equivalent chemical composition] tested has demonstrated validation of the connection TLE at the stated CAL.

If each of the tests conducted at the 90 % level sealability testing pass, the 95 % level sealability testing tests shall be performed. If the tests conducted at the 95 % level sealability testing fail, the connection has conformed to the stated assessment level at a 90 % level sealability testing. If each of the tests conducted at the 90 % and 95 % level sealability testing pass, the connection has conformed to the stated assessment level at the 95 % level sealability testing. See Figures 4 through 7 for the test requirements and test sequence.

Limit load tests have termination criteria as defined in 7.4.2. The loads at test termination shall be compared to the anticipated failure load calculated by the manufacturer as defined in A.1.5. Limit loads shall exceed the CEE. If the limit load does not exceed the CEE, the CEE may be revised such that the resultant CEE is now smaller than the limit load results and no further testing is required. If a failed 90 % or 95 % level sealability test specimen does not allow continuing to the limit load test, a replacement specimen shall be manufactured to complete the limit load test. For the replacement specimen, use the specified final makeup (FMU) and bake-out for that specimen; however, sealability testing is not required prior to the limit load test.

5.3.2.3 Test Results that Do Not Conform to Stated Connection Assessment Level

When the test results do not conform to the requirements of the TLE tests, the results may be evaluated for either: (1) a connection design revision followed by a full retest or (2) a reduced CEE, followed by a retest of any test specimen(s) that have not already achieved a larger CEE.

In case of the malfunctioning of testing facilities or test execution, which is not related to product design, neither a connection design revision, CEE revision or limit load revision is required, but the test specimen(s) or replacement test specimen(s) shall be retested in full. Any event not conforming to acceptance criteria shall be reported. The number of retests and the need for the retests shall be included in the test report.

5.3.2.4 Reporting of Test Results

For each test conducted, the results shall be reported in accordance with Section 9. Leakage, whether during the TLE hold periods or with the equipment, regardless of volume or rate, shall be reported on the datasheets and identified on the pressure plots. During load changes, displacement changes may be a function of volumetric changes and not leakage. Record displacement levels prior to and after load changes.

5.4 Calibration and Accreditation Requirements

5.4.1 Accreditation

The laboratory conducting these tests shall either:

- a) be accredited by a recognized national or international accreditation body or
- b) comply in full with 5.4.2 to 5.4.5.

5.4.2 Equipment Calibration

Before testing begins, ensure that the load frames to be used for the tests have been calibrated to traceable national standards. In addition, based on the connection manufacturer's or test laboratory's experience, measuring and recording instruments, such as pressure gauges, shall be calibrated periodically. The test laboratory standards for calibration and each calibration shall be documented. Copies of current calibration test reports for the load frame, pressure, and torque measuring devices shall be included in the detailed test report.

Equipment calibration during a test program may be appropriate based on the required test loads and past equipment usage.

The test lab should have a procedure to ensure that the thermocouple temperature readings are accurate.

5.4.3 Annual Load Frame Calibration

Each load frame used in an axial load or combined load test shall be calibrated in both tension and compression modes at least annually with device(s) (i.e. load cells) traceable to national standards.

The calibration should consist of two passes of a minimum of 10 equal increments ranging from the minimum calibration load to the maximum calibration load (defined as the "loading range"). The calibration range of the load frame shall cover the range of loads that will be applied in the test program. The maximum frame calibration load shall be greater than the maximum anticipated failure load of the connection/pipe being evaluated.

The error, E_r , and the percent error, E_{rp} , are calculated as follows:

$$E_r = F_i - F_f \quad (1)$$

$$E_{rp} = 100 \frac{E_r}{F_f} \quad (2)$$

where

F_i is the indicated frame load;

F_f is the actual frame load.

The percent error for the loads within the loading range of the frame (at least 10 % to 100 % of tension/compression capacity) shall not exceed ± 1.0 % when approached from both directions in tension and compression (see Annex E for an example).

5.4.4 Load Frame Verification

In the event that the load frame is subjected to unusual loads, such as applying a load beyond the calibration range or if a failure occurs at an unexpected load that could indicate a calibration problem, a verification bar shall be used to verify the load frame calibration. This verification bar shall be traceable to national standards bodies and certified triennially. In lieu of using the verification bar, a full annual calibration may be performed.

5.4.5 Pressure Transducer Calibrations

Each pressure transducer shall be calibrated at least annually. The percent error for pressures within the loading range shall not exceed $\pm 1.0\%$ of full scale. Appropriate pressure transducers should be selected and used based on the maximum anticipated test pressure being monitored.

5.5 Material Characterization

5.5.1 General

The pipe shall be mechanically tested to determine the yield strength for calculation of the pipe body reference envelope for each test specimen. The coupling stock shall be mechanically tested to determine its yield strength. The pup and coupling stock mechanical test data should be considered in the determination of the CEE for each test specimen.

The mechanical properties of the pipe and coupling stock shall be characterized by a documented procedure consistent with the specification for the material. Typically this is API 5CT for low alloy steel or API 5CRA for corrosion-resistant alloys (CRAs). For connections machined on line pipe, the procedure shall be in accordance with API 5L.

Report the material property data required on the material property datasheet, Figure B.3.

For ambient temperature longitudinal tensile testing, refer to API 5CT and ASTM A370. For elevated temperature longitudinal tensile testing, refer to ASTM E21.

For elastic modulus, refer to API 5C3. For specific materials, elastic modulus may be determined at ambient and elevated temperatures and used where applicable. ASTM E111 may be used as a reference for performing these evaluations.

Measure wall thicknesses of each pup and establish the minimum wall and minimum average wall for each. Use these data for calculation of the pipe body reference envelope for each test specimen (see 5.5.3 and Figure B.5).

Measure OD of each pup and establish the maximum average OD for each. Use these data for calculation of the pipe body reference envelope for each test specimen (see 5.5.3 and Figure B.5).

For test couplings, measure the OD and establish a minimum OD and average OD for each (see 5.5.3 and Figure B.5).

5.5.2 Material Property Tests

5.5.2.1 Material Test Coupons

MTs shall be extracted from each length of pipe and coupling stock used to manufacture the test specimens. MTs shall be extracted from the mother joint or coupling stock mother tube (regardless of their length) adjacent to the connection of each test specimen pup or at least one test coupling when applicable.

See Figure B.1 for recommended options for mapping. For each specimen, the coupons adjacent to the test connection shall be used for the determination of the ambient temperature yield strength (see 5.5.2.5). In addition, at least one of the MTs from each mother joint or coupling stock mother tube shall be used to determine the corresponding elevated temperature scaling factor for that mother joint (see 5.5.2.6).

The MTs shall be traceable to the mother joint or coupling stock mother tube and the axial location within the tube.

5.5.2.2 Longitudinal Tensile Test Specimens

Longitudinal material property tests shall be conducted on tensile test specimens. Tensile test specimens shall be cut from MTs.

Extraction of longitudinal tensile test specimens from each MT is as follows.

- a) For determining the ambient temperature yield strength, machine at least four specimens for ambient temperature testing (see 5.5.2.5). The longitudinal tensile test specimens shall be full-body wall strips unless the full-body strips are beyond the capacity of the testing equipment or otherwise impractical; then round tensile test specimens may be used.
- b) If elevated temperature testing is performed on the MTs, machine at least four specimens for ambient temperature testing and at least four specimens for elevated temperature testing to determine the elevated temperature scaling factor (see 5.5.2.6). Identical specimen geometry shall be used for both ambient and elevated testing. Round tensile specimens are the most practical, and use of the largest practical size in accordance with API 5CT and ASTM A370 is recommended.

At least one longitudinal tensile test specimen shall be taken from each quadrant of the MT. For elevated temperature testing, circumferential locations of the ambient and elevated temperature longitudinal tensile test specimens within each MT shall be adjacent (as close as practical).

The longitudinal tensile test specimens and results of the material property tests shall be traceable to the MT. The circumferential locations shall be traceable within the MT. Sketches of the geometries and axial and circumferential locations selected for the ambient and elevated (if performed) longitudinal tensile test specimens from the MT shall be shown in the material property datasheet, Figure B.3.

The recommended layout for test specimen pups or test couplings and MTs shown in Figure B.1 provides the material strength directly adjacent to the connection of each test specimen pup or test coupling. If the test specimen pups, the test couplings, or the MTs are not cut as shown in Figure B.1, the manufacturer shall modify the material property datasheet shown in Figure B.3 and shall provide a sketch similar to Figure B.1 showing the actual locations.

See 6.3.3 to ensure sufficient pipe and coupling stock is tested and that mechanical properties meet the requirements stated in this RP.

5.5.2.3 Transverse Tensile and Compression Test Specimens

In cases where the sample material exhibits strength anisotropy (e.g. cold-worked CRA), it shall be characterized. Testing may be performed as necessary to characterize the anisotropy. If anisotropy test data pertinent to the specific manufacturing process, material grade and size are available, these data may be used instead of testing if agreed with the purchaser. These supporting data shall be documented in the test report.

When testing is performed to characterize the anisotropy, axial compression yield values, axial tensile yield values, and transverse tensile yield values shall be determined.

Extraction of test specimens from the MT is as follows.

- a) For determining the transverse scaling factor, machine at least four longitudinal tensile test specimens and four transverse specimens for ambient temperature testing (see 5.5.2.7). Identical specimen geometry shall be used for longitudinal and transverse testing. Round test specimens are the most practical and shall be the largest practical size in accordance with API 5CT and ASTM A370.
- b) For determining the longitudinal compressive scaling factor, machine at least four longitudinal tensile test specimens and four longitudinal compressive specimens for ambient temperature testing (see 5.5.2.7). ASTM E9 should be used for guidance to conduct ambient temperature compression testing.

If transverse tensile or compression tests are performed, the manufacturer shall provide a documented procedure (to be included in the test report) detailing the sampling locations, test specimen geometry, and test parameters. The minimum yield strength values from these tests may be used to determine the CEE as long as this is clearly documented in the test report.

5.5.2.4 Minimum Test Scope

5.5.2.4.1 Material Property Tests

The following shall apply to material property tests.

- a) At least four longitudinal tensile tests (one from each quadrant) at ambient temperature from each MT.

At least four longitudinal tensile tests (one from each quadrant) at elevated temperature from one of the MTs from within the middle 50 % of the mother joint subjected to elevated temperature testing.

- b) For ambient temperature tensile tests, pull rates shall be at a maximum strain rate of 0.005 in./in./min.
- c) For elevated temperature tensile tests, pull rates shall be at a maximum strain rate of 0.003 in./in./min.

5.5.2.4.2 Elevated Temperature Test Temperatures

The following shall apply to elevated temperature test temperatures.

- a) For CAL II this is 302 °F (150 °C), +0 °F/−9 °F (+0 °C/−5 °C).
- b) For CAL III and CAL IV this is 383 °F (195 °C), +0 °F/−9 °F (+0 °C/−5 °C).

5.5.2.4.3 Tensile Test Report

The following shall apply to the tensile test report.

- a) Acquired stress/strain plot from zero strain to 2 % strain or to specimen failure, whichever occurs first.
- b) Yield strength as defined by API reference for materials and grades defined in API 5CT, API 5CRA, or API 5L. Additionally, the 0.2 % offset proof stress shall be reported.
- c) Ultimate strength.
- d) Total elongation.

See C.2, Section 3 for reporting requirements.

5.5.2.4.4 Temperature Monitoring Requirements

For each ambient temperature test, the temperature shall be recorded. For each elevated temperature test, monitor the actual test specimen temperature with a thermocouple attached to the material test specimen, and include the temperature history data in the test report.

5.5.2.5 Ambient Temperature Material Yield Strength

The ambient temperature material yield strength for each test specimen pup or test coupling is established as the minimum ambient temperature material yield strength of the MT adjacent to the test specimen pup or test coupling.

The material yield strength of a test coupon shall be established as the lowest result obtained from the testing of the four or more longitudinal tensile test specimens taken from that MT in accordance with 5.5.2.2. When

both strip and round bar tests results are available, only strip data shall be used for the determination of the longitudinal material yield strength. In the event that a result is below the SMYS of the grade, two additional tensile tests may be performed on the same material coupon from the same quadrant. If the yield strength of either of the additional tests is below the SMYS, the joint shall not be used.

5.5.2.6 Elevated Temperature Scaling Factor

The minimum basis for definition of the elevated temperature scaling factor is a single MT taken from within the middle (between 25 % and 75 % of the total length as measured from an end) of the mother joint or coupling stock mother tube.

The elevated temperature scaling factor for the mother joint or coupling stock mother tube is the ratio between the average of all longitudinal tensile test yield strength results at elevated temperature and the average of all longitudinal tensile test yield strength results at ambient temperature for the specimens cut for elevated temperature scaling factor determination. The ambient temperature strip test results shall not be used for the determination of the elevated temperature scaling factor. Test specimens used for the elevated temperature scaling factor shall be of the same size and geometry as specified in 5.5.2.2. For elevated temperature scaling factor determination of the mother joint or coupling stock, all valid test results from tensile test specimens shall be used.

The elevated temperature scaling factor shall be used to determine the elevated temperature pipe body reference envelope for each test specimen taken from the mother joint.

5.5.2.7 Anisotropy Scaling Factor

The transverse tensile anisotropy scaling factor for the mother joint or coupling stock mother tube is the ratio between the average of all transverse test results and the average of all longitudinal tensile test results. The ambient temperature strip test results shall not be used for the determination of the transverse tensile anisotropy scaling factor. Test specimens used for the transverse anisotropy scaling factor shall be of the same size and geometry as specified in 5.5.2.3.

The compression anisotropy scaling factor for the mother joint or coupling stock mother tube is the ratio between the average of all longitudinal compressive test results and the average of all longitudinal tensile test results. Only the round bar longitudinal tensile test data and the ASTM E9 compression test data should be used for the determination of the compression anisotropy scaling factor (see 5.5.2.3).

Use of anisotropy scaling factors already obtained from prior testing may be acceptable if agreed with the purchaser and supported by data pertinent to the manufacturing process, material grade, and size (see 5.5.2.3).

These scaling factors may be used for determining the CEE.

5.5.3 Material Dimensional Measurements

5.5.3.1 General

For each test specimen pup, the critical dimensions required for calculating the pipe body reference envelope shall be measured and recorded (see Figure B.5).

For each test specimen pup, establish five planes along the pup axis as follows (see Figure B.2).

- a) Establish plane #1 at 3 in. from the end of the grip length or test cap.
- b) Establish plane #5 at 3 in. from the box face (on plain end pin pups), 3 in. from the end of integral flush box connections, or 3 in. from the end of the expansion/upset transition zone [on integral joint (IJ) boxes and upset pins/boxes].
- c) Establish planes #2, #3, and #4 equally spaced between plane #1 and plane #5.

In each of the five planes, find the location of the minimum wall. Mark the location on the pup as 0° and record the minimum wall reading (see Figure B.5).

In each plane, mark seven additional locations equally spaced around the circumference of the pup as 45°, 90°, 135°, 180°, 225°, 270°, and 315°. Measure and record the wall thickness at each location in each of the five planes (see Figure B.5).

The manufacturer is responsible for measuring and recording dimensions required to establish the CEE.

5.5.3.2 Minimum Wall

For each test specimen pup, the minimum wall is established as the smallest of the five minimum wall measurements taken for each measurement plane (see Figure B.5).

The established minimum wall for each test specimen is the smallest of the minimum walls between the two pups. The test specimen established minimum wall shall be used to calculate the actual VME curve at ambient temperature (see 7.3.1.2.3).

5.5.3.3 Minimum Average Wall

From the eight wall measurements in each of the five planes on each test specimen pup, determine and record the average wall for each measurement plane (see Figure B.5).

For each test specimen pup, the minimum average wall is established as the smallest of the five average walls determined in the five measurement planes (see Figure B.5).

The established minimum average wall for each test specimen is the smallest minimum average wall between the two pups. The test-specimen-established minimum average wall shall be used to calculate the actual VME curve at ambient temperature and the actual API collapse curve at ambient temperature (see 7.3.1.2.3).

5.5.3.4 Maximum Average OD

From the four OD measurements in each of the five planes on each test specimen pup, determine and record the average OD for each measurement plane (see Figure B.5).

For each test specimen pup, the maximum average OD is established as the largest of the five average ODs in the five measurement planes. The established maximum average OD for each test specimen is the largest average OD between the two pups.

The test-specimen-established maximum average OD shall be used to calculate the actual VME curve at ambient temperature and the actual API collapse curve at ambient temperature (see 7.3.1.2.3).

5.6 Makeup and Breakout Procedures

5.6.1 Principle

Makeup and breakout procedures, thread compound, and the surface treatment used during testing should be consistent with the manufacturer's RP for field usage.

5.6.2 Makeup Thread Compound

The connection manufacturer shall specify the type and amount, with tolerances (default tolerance is ± 1 g), of thread compound that shall be applied to the connection, as well as the areas to which the thread compound shall be applied. These thread compound criteria shall be the same as those used for field applications. The same thread compound shall be used for each test specimen. Preferably, the maximum and minimum quantities should be specified as mass for the thread compound to be used in testing. The

specific gravity of the thread compound used shall also be provided on the datasheet. In addition, the manufacturer shall provide photographs and descriptions of how to apply the thread compound for mill and field applications. This includes photographs of connections with minimum and maximum thread compound.

It is recognized that connections exist in the industry that have surface treatments that do not require thread compound and therefore 5.6.2 may not apply. However, additional testing may be conducted with a combination of thread compound and surface treatment to verify performance.

5.6.3 Makeup Torques

The makeup torques specified in Section 7 are either the maximum or minimum torque recommended by the manufacturer. For a high specified torque, the test specimen makeup is acceptable if the torque is more than the sum of 80 % of the maximum torque recommended by the manufacturer plus 20 % of the minimum torque recommended by the manufacturer. For a low specified torque, the test specimen makeup is acceptable if the torque is less than the sum of 80 % of the minimum torque recommended by the manufacturer plus 20 % of the maximum torque recommended by the manufacturer.

For each of the single makeup test specimens in a test series, if the actual makeup torque is less than the manufacturer's minimum because of a testing error, the specimen may be broken out and reassembled a second time to achieve the manufacturer's minimum torque. If the second makeup also does not achieve the manufacturer's minimum torque, that specimen may be tested as is or it shall be replaced.

5.6.4 Makeup Procedure

Make up each connection in the manner described below. Record the results in Figure B.4.

For each makeup, clean and dry the connection completely, then weigh and record the amount of thread compound applied to each connection member (pin and coupling side or integral box). Monitor and record makeup and breakout torques on torque-versus-turn plots. The turn resolution shall be at least 1/1000th of a turn. Torque-versus-turn plots for makeups of Section 7 and any additional makeups considered relevant shall be included in the full test report (see Section 9 and Annex C). At the time of makeup, annotate each plot to indicate the test specimen, pin end and box end, makeup number, date, time, and any other observations.

Connections should be made up using tongs and tong dies typical of those used in the field. Additional attention should be exercised in selecting the type of tongs and dies used on CRA materials. Vertical makeup should be used. For coupled connections, floating of the coupling is prohibited (i.e. each side shall be made up separately). Photograph makeup equipment and at least one connection being made up. In addition, the makeup speed shall be recorded for each makeup. Make and breaks should be conducted with the tong in low gear. When gripping couplings (or boxes), clamping forces should be controlled to prevent adverse distortion of the internally threaded member.

When performing the makeup and breakout procedure, it is recommended to install a plug in the coupling end that is not being made up to help avoid damage to that connection by providing additional rigidity to that coupling end during the makeup of the other coupling end. The plug should have a thread design compatible with the test specimen; however, achieving specific geometric tolerance is not required. As an alternative to a plug, a hand-tight pin may also be used.

Use of strain gauges is optional (see 5.9.3).

5.6.5 Breakout Procedure

Break out the connection test specimen with the same tongs and instrumentation as in 5.6.4 in accordance with the manufacturer's procedure. Record the results in Figure B.4.

5.6.6 Breakout Refurbishment

Following each breakout, pins and boxes may be refurbished using only techniques, equipment, and tools stipulated by the connection manufacturer for field use. Such repairs shall be fully documented, including repair time. Any galling or other nonconformity shall be reported. A galling evaluation, including a clear description of the size and nature of the damage, shall be part of the final report. Photographs shall be made of the galled surface, repaired surface, repaired surface after the next breakout, and the repaired surface after the final breakout and shall be included in the final report.

5.6.7 Test Specimen Connection Inspection

Inspect the test specimen connections carefully following each breakout. Evaluate and document on the torque-versus-turn plots any correlation with observed connection galling. On the torque-versus-turn plots, document any observations or variances that contributed to other makeup concerns (coupling or pin spinning in tong dies, computer error/electrical spike that results in no torque-versus-turn printout, etc.).

5.6.8 Post Final Makeup Drift Testing

After the final makeup of each specimen and before further testing, a drift test shall be performed in accordance with 7.2.4. The purpose is to confirm a connection will drift after make-and-break testing.

5.7 Internal Pressure Leak Detection for TS-B and TS-C Setup

5.7.1 Principle

Leak detection requirements are critical for those connections that are required to be gas or liquid tight. Two proven methods of leak detection are described in 5.7.5 and 5.7.6 for use on different types of connections; however, any method of leak detection that can be calibrated to known traceable standards and meets the sensitivity requirements outlined in 5.7.4 may be used. For TS-B and TS-C, casing and tubing specimens that are subjected to internal pressure shall be monitored with a system capable of trapping and measuring leakage volume or flow rate.

Displacements during load changes shall be recorded on the datasheets; however, these displacements are not considered as a connection leak. Pressure sealing acceptance criteria are shown in 8.3. Connection leaks shall be identified on the pressure plots.

5.7.2 Pressurization Media

For CAL II, CAL III, and CAL IV, internal pressure tests to validate the TLE shall be conducted with dry nitrogen. For CAL I, tests with internal pressure to verify the TLE shall be conducted with liquid or dry nitrogen as specified in the test plan. By agreement between the parties of the test, a helium tracer gas may be added.

For the elevated temperature cycles in TS-B, and TS-C, the requirements in 5.10 apply.

5.7.3 Internal Pressure Leak Detection Sensitivity

The monitoring and measuring system for internal pressure leak detection shall meet a minimum leak indication sensitivity of $0.9 \text{ cm}^3/15 \text{ min}$ time period using a graduated cylinder of 0.1 cm^3 graduations or a sensitivity of $1 \times 10^{-4} \text{ cm}^3/\text{s}$ under standard conditions for gas chromatograph or spectrometer system. If helium tracer gas is used, the graduated cylinder based system shall have the capability of capturing the accumulated gas for the analysis of helium content to verify or discount leak events.

When using a graduated cylinder, take care to compensate for changes in barometric pressure or other non-test relevant events because these changes can affect the leak detection sensitivity. It is recommended that prior to beginning any tests, a separate graduated cylinder (see Figure 11) replicating the leak detection device be set up. This separate graduated cylinder can be used during analysis to determine whether a connection is leaking or whether the change is due to a change in barometric pressure. When used, the separate graduated cylinder shall contain a gas bubble consistent with the size of the bubble in the inverted graduated cylinders of the connections being monitored.

5.7.4 Leak Indicators

Leak indicators can be evaluated regarding their source if there is reason to believe the indication is not from the connection. A sensor calibrated to detect helium may be used to verify that any bubbles detected are coming from the pressure medium and not from thread compound de-gassing or from thermal expansion of the connection or test equipment. Evaluation of the leakage source shall be based on conclusive analysis of the leakage gas. If leakage is generated from a source other than the connection (e.g. the end caps), the source of the leakage shall be repaired and testing continued. Report leaks and their source (e.g. pressure fitting, valve, connection). Leak indicators shall be reported and the basis for discounting connection leakage clearly explained in the test report.

5.7.5 Internal Pressure Leak Trap Device

5.7.5.1 Principle

During the pressure test, the connection test specimen shall contain one or more of the internal pressure leak trap devices described in 5.7.6.2 through 5.7.6.4. When the tests will be at elevated temperature, the leak trap device materials shall be rated for a temperature above the maximum test temperature.

5.7.5.2 Collared Leak Trap Device

A collared leak trap device consists of an O-ring held against the face or OD of the box by a ported collar containing a flange with at least four bolt holes. Four longitudinal bolts maintain the collar tight against the face for sealing. A second O-ring is used to seal the collar against the pipe body using a separate bolted ring as shown in Figure 8.

5.7.5.3 Flexible Boot Leak Trap Device

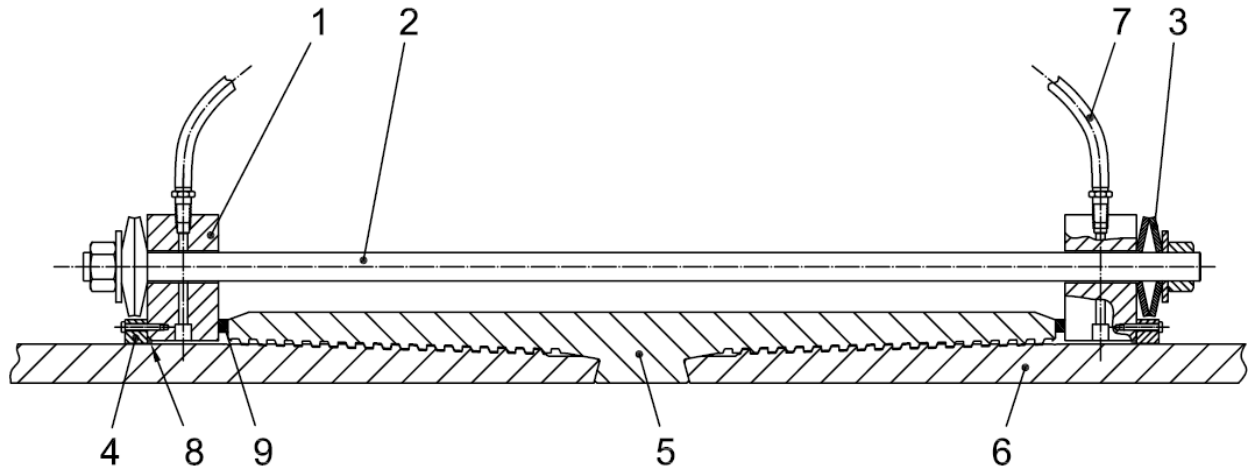
A flexible boot trap device consists of a flexible material, such as silicone, that encapsulates the end of the box. A sealant is used between the pipe OD, box OD, and the boot. Hose clamps are used to secure the boot to the pipe and the box OD. A tube is placed between the boot and pipe OD, using the sealant to ensure that escaping gas exits by the boot as shown in Figure 9.

5.7.5.4 Ported Box Leak Trap Device

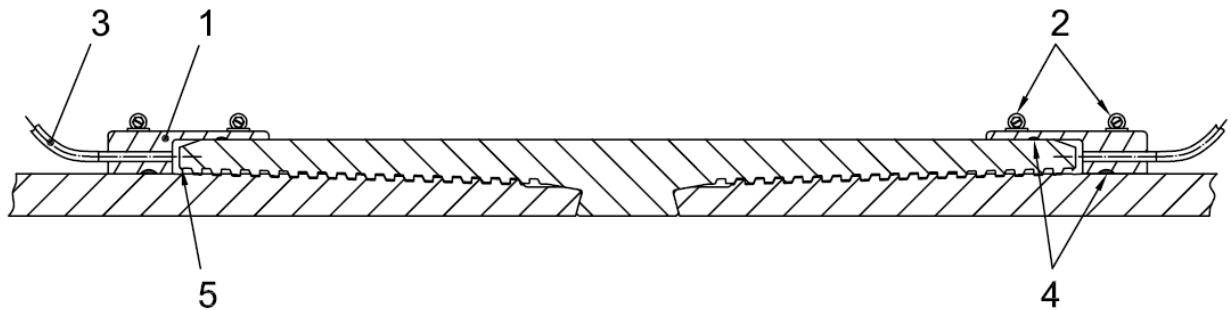
A vent hole is drilled through the box over the pin run-out threads near the end of the box face to allow escaping gas to exit the connection. The hole is tapped and fitted with a threaded adapter to which a flexible hose is attached. The face of the box shall be sealed to prevent any gas from escaping out of the end of the box as shown in Figure 10.

Assemble the ported box (Figure 10) in the following manner:

- a) drill, tap, de-burr, and plug ports before connection makeup;
- b) assemble connection;
- c) install threaded fittings into holes using thread sealer [such as polytetrafluoroethylene (PTFE)];
- d) clean and seal the ends of the coupling with silicone sealant or equivalent;
- e) allow sealant to cure;
- f) ports may be close to metal-to-metal seal.

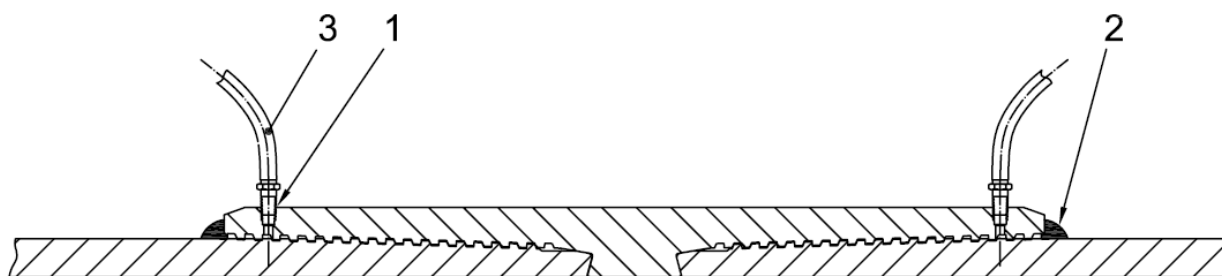
**Key**

- 1 metallic flange
- 2 threaded rod
- 3 springs
- 4 threaded nut
- 5 coupling
- 6 pipe
- 7 flexible hose (heat resistant for elevated temperature tests)
- 8 O-ring
- 9 flat face gasket

Figure 8—Collared Leak Trap Device for Internal Pressure Leak Detection**Key**

- 1 flexible boot
- 2 hose clamps
- 3 metal tube or flexible hose (heat resistant for elevated temperature tests)
- 4 sealant
- 5 small gap for good leak-detection sensitivity

Figure 9—Flexible Boot Leak Trap Device for Internal Pressure Leak Detection



Key

- 1 tapped hole in run out threads with threaded fitting
- 2 sealant
- 3 flexible hose (heat resistant for elevated temperature tests)

Figure 10—Ported Box Leak Trap Device for Internal Pressure Leak Detection

5.7.6 Internal Pressure Leak Detection by Bubble Method for Gas Testing

5.7.6.1 Principle

A leak detection system based on the bubble method is shown in Figure 11. The system is based on capturing gas that passes through a connection and collecting the gas in a container for measuring the volume. The main components of the system are as follows.

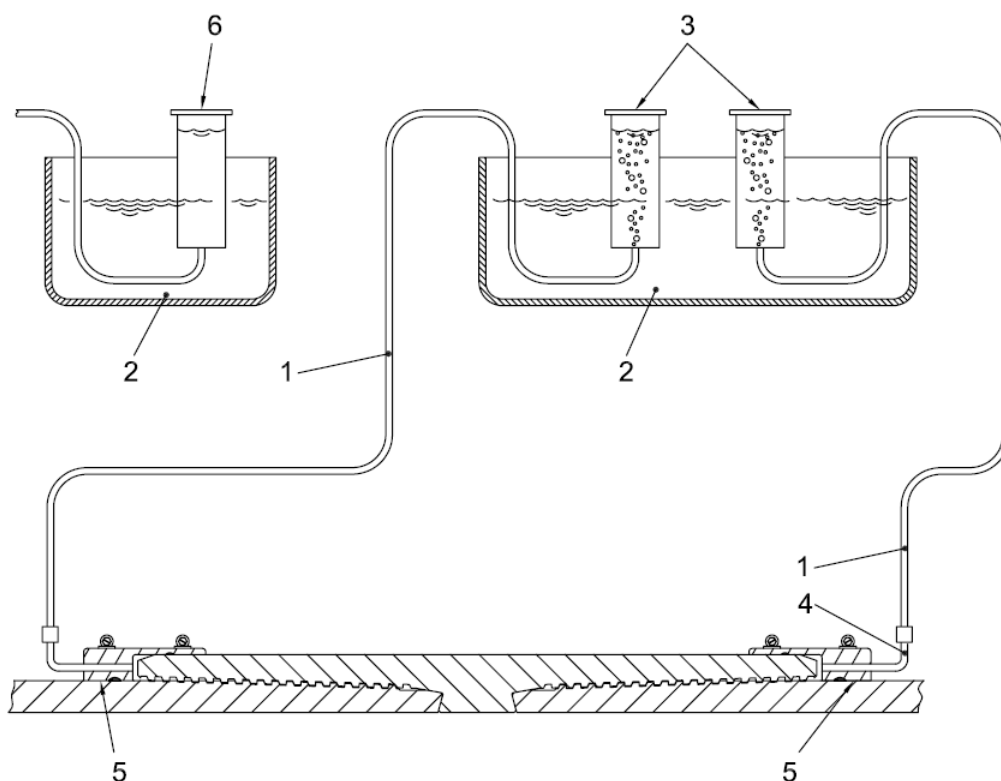
- a) A means of trapping the gas, such as the leak trap devices described (see 5.7.5).
- b) A tube or flexible hose that connects the leak trap device to a bubble collection tube.
- c) A bubble collection tube that consists of a clear graduated cylinder with 0.1 cm³ or smaller-scale divisions.
 - 1) The cylinder is filled with water and a flexible hose is placed inside the open end of the cylinder.
 - 2) The cylinder and the end of the hose are submerged in a container of water and then inverted (see Figure 11).
- d) Pressure sealing acceptance criteria are stated in 8.3.

Leakage is visually detected if bubbles rise in the cylinder. The source of the leak shall be evaluated to determine if the leakage is the result of a connection leak or from some other source, such as thread compound de-gassing (see 5.7.4).

5.7.6.2 Pressure Test of Leak Trapping Devices

Each trapping device shall be tested as follows.

- a) Check sealant and fitting for leaks by attaching a hose to a pressure supply at the beginning and end of the test:
 - 1) apply a gas pressure of 1 psig to 2 psig air or nitrogen,
 - 2) close off from supply and observe pressure gauge for a decrease in pressure.
- b) Tighten or repair trapping device as necessary.
- c) Periodically remove fitting, clean hole as necessary, and re-pressure test system as above.



Key

- 1 flexible hose (heat resistant for elevated temperature tests)
- 2 water tank
- 3 graduated cylinders
- 4 heat-resistant tube
- 5 leak trap devices
- 6 dummy graduated cylinder (same size and height above top of water as cylinders, see key item 3)

Figure 11—Example Configuration of Internal Pressure Leak Detection by Bubble Method

5.7.6.3 System Verification for Bubble Method

The following concern system verification for the bubble method.

- a) Verify internal pressure leak detection systems prior to a test program and after completing the test program by testing for leaks and assessing sensitivity. In the event that leakage is discovered in the leak detection system after a test is conducted, tests conducted since the last leak detection system evaluation shall be repeated.
- b) Test the system for leaks by applying 1 psig to 2 psig air or nitrogen gas pressure. When the pressure stabilizes, close off the gas supply. Observe the pressure gauge for 2 minutes for stability. Any drop in pressure indicates a system leak. Locate and repair any system leaks. This sensitivity efficiency shall be reported and may be used to evaluate indications. Note that sensitivity of the system may be improved by minimizing hose length.
- c) Determine the sensitivity efficiency of the bubble leak detection system by introducing air and measuring the output air in each bubble tube. Inject the air in 1 cm³ increments up to at least 10 cm³. Determine the average relationship of output volume to input volume by plotting the data as shown in Figure 12. The initial amount of input air required to start output air in the bubble tube (pre-charge) shall be recorded, but does not affect the calculated leak rate and is therefore not considered in this sensitivity efficiency.

The sensitivity efficiency shall be at least 70 %; if less than 70 %, reconfigure the system to increase sensitivity. This sensitivity efficiency shall be used to correct observed leak rates and volumes during test execution according to the following:

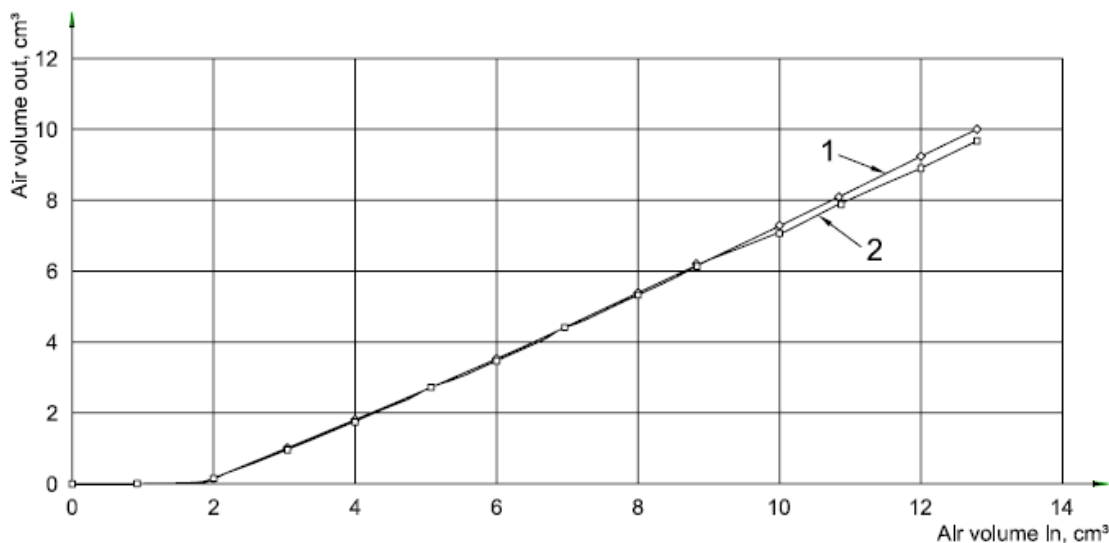
$$q_{ac} = \frac{q_o}{\eta_{lds}} \quad (3)$$

where

q_{ac} is the actual leak rate to be reported;

q_o is the observed leak rate;

η_{lds} is the leak detection system efficiency (slope of the lines in Figure 12).



Key

- 1 specimen end A
- 2 specimen end B

Figure 12—Example of a Plot for Determining Leak Detection Sensitivity

5.7.6.4 Start of Test

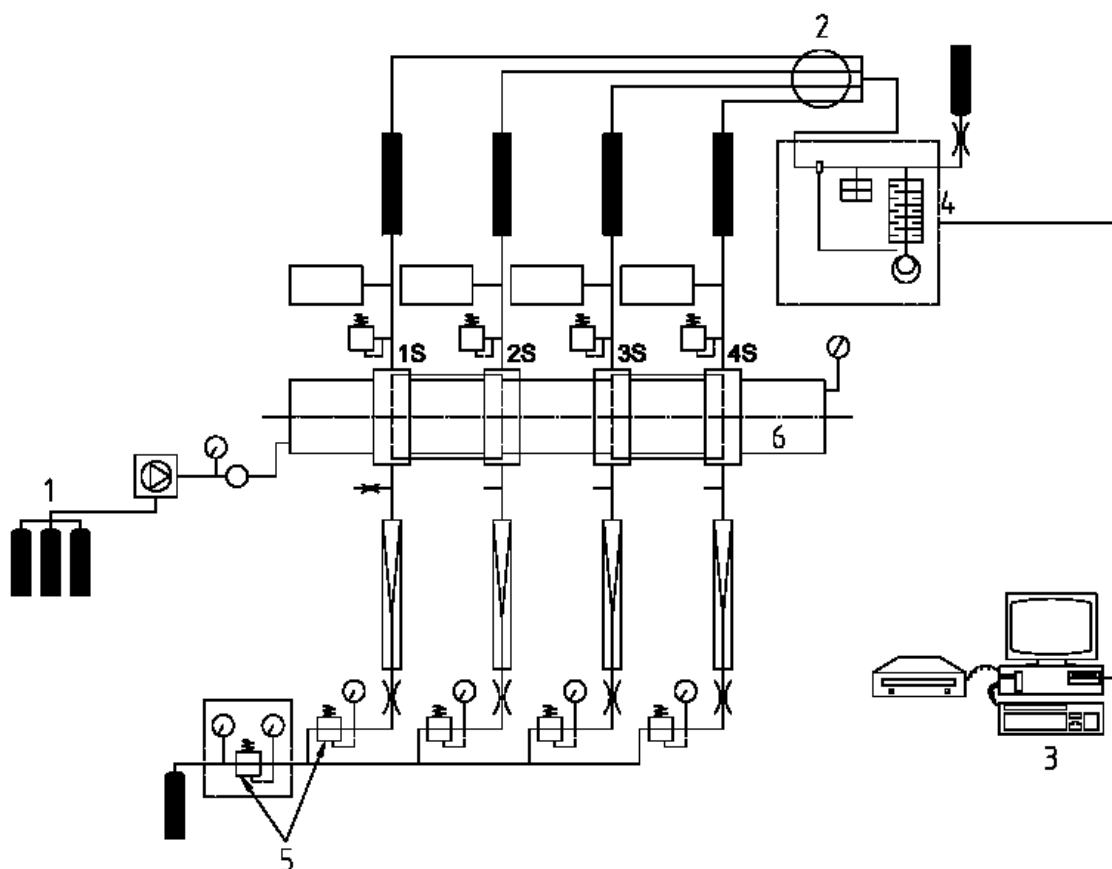
Before starting internal pressure tests, pre-charge each leak detection system by injecting air into the system near the box thread until a small amount of air collects in the bubble tube. Record this volume as the initial amount of gas that is subtracted from any additional gas collected in the tube. This pre-charge volume shall be sufficient to lower the water level to the scales on the graduated cylinder prior to the initiation of the test sequences and to demonstrate that the lines are not plugged.

5.7.7 Internal Pressure Leak Detection by Helium Mass Spectrometer Method

5.7.7.1 Principle

A leak detection system using a helium mass spectrometer (see Figure 13) includes the following:

- a) a means of trapping the gas;
- b) a tube or flexible hose connecting the leak trap device to a carrier gas line;
- c) a pure nitrogen carrier gas line that connects to a mass spectrometer;
- d) a helium mass spectrometer (where the mass spectrometer uses a sniffing method of leak measurement, special care is necessary to ensure the sniffer is working properly at atmospheric pressure).



Key

- 1 internal pressure source
- 2 sampling valve
- 3 data logger
- 4 mass spectrometer detector
- 5 carrier gas regulators
- 6 test specimen (shown with two couplings and four connections: 1S, 2S, 3S, and 4S)

Figure 13—Example Configuration of Leak Detection by Helium Mass Spectrometer Method

5.7.7.2 System Accuracy

The helium leak measuring system shall be capable of measuring a total effective leak rate of $1 \times 10^{-4} \text{ cm}^3/\text{s}$ under standard conditions or lower leakage rate.

5.7.7.3 Calibration

The complete system shall be calibrated to the equipment supplier's recommendation and at least once annually using a certified calibrated leak source. The calibrated leak source shall be used in place of a test specimen with each component of the leak detection system in place.

5.7.7.4 Multiple Specimen Leak Measurement

A manifold scanner can be used to test multiple connections or specimens. Minimum required sniffing time varies with equipment and shall be determined and demonstrated before starting the test. Each line shall be sniffed no less than once per minute.

5.7.7.5 System Verification

Before each test, flush the system with nitrogen. Inject a documented amount of helium at or near the leak trap device to ensure the detector is finding the helium. Sniff for helium through the complete line and leak trap device. Check for proper helium content of the gas, demonstrating that the lines are not plugged. Finally, flush the lines again to ensure that the test is starting with a non-contaminated system.

5.8 Leak Detection for TS-A Setup

5.8.1 Tests Performed at Ambient Temperature

5.8.1.1 Principle

The casing and tubing connections shall be subjected to internal and external pressure at ambient temperature within a system capable of detecting the internal and external pressure leakage. External pressure leak detection is recognized as more difficult and less accurate than internal pressure leak detection.

Though it is desirable to utilize leak detection methods similar to 5.7.6 and 5.7.7, these methods are not possible due to the presence of the external pressure vessel. As a result, TS-A leak detection at ambient temperature for internal pressuring testing shall be performed in accordance with 5.8.1 if the vessel remains on the specimen during internal pressure testing or 5.7 if the vessel is removed.

Displacements during load changes shall be recorded and reported; however, these displacements are not considered as a connection leak. Pressure sealing acceptance criteria is in accordance with 8.3. Connection leaks shall be identified on the pressure plots.

To validate suspected leaks, perform additional tests to confirm the rate and source. In the case of a suspected internal pressure leak, the external pressure chamber should be removed so that each connection in the test specimen assembly can be evaluated separately. In these cases, displacements observed with the external pressure chamber shall be recorded, but only the results without the external pressure chamber shall be used to evaluate a load point with a suspected leak.

In the context of the leak verification without the external pressure chamber, the load point(s) with a suspected leak shall be retested arriving to the load point from the same direction (CCW or CW) as the previous evaluation performed with the external pressure chamber. In case a load point showed suspected leaks in both directions during the previous testing sequence, leak verification without the external pressure chamber shall be performed for the previous load point from both directions. The hold period for leak verification shall be the longest hold period for that particular load point during that particular test sequence.

For practical reasons, in the case of a suspected leak with the external pressure chamber, it is allowed to continue the test with the external pressure chamber until the test sequence is completed, and perform the leak verification without the external pressure chamber thereafter.

The evaluation performed without the external pressure chamber shall be considered as part of the test and not a deviation.

5.8.1.2 Pressurization Media

Reference 5.7.2 for pressurization media.

External pressure tests performed at ambient temperature shall be conducted with water or an appropriate pressurization medium.

5.8.1.3 Internal and External Pressure Leak Detection Sensitivity and Verification

For TS-A tests at ambient temperature, the leak detection sensitivity for internal and external pressure testing shall follow 5.7.6.3, when calibrating the chamber and sample, respectively. The sensitivity shall be recorded and documented in accordance with 5.7.6.3.

To assist with leak detection, tracer dyes may be used in the fluid or the coupling may be ported in the area between the metal seal and the first thread start on the pin. Another option is to measure the length of time required for fluid to broach a thread seal. This length of time would then be used to determine the minimum hold times for current 1-hour holds performed after any external pressure tests.

5.8.1.4 Ported End Caps

Connection test specimen end caps should have holes that allow the inside of the specimen to be filled with liquid. These holes should have high-pressure fittings able to contain internal pressure during internal pressure tests. Normally, two holes are required, i.e. one for water inlet and one for air exit (air bleed). The air bleed hole should be at the opposite end of the specimen from the water inlet hole. The bleed hole should be located in the end cap to allow the removal of air from the inside of the specimen. If the air is not removed from the external pressure chamber, it may result in long stabilization periods and/or faulty results with regard to sealing of the connection. Therefore, efforts shall be taken to remove air from the external pressure chamber, from the test specimen, and from leak detection lines. Having the inlet and outlet ports in the proper locations, tilting the specimen during filling the specimen or external pressure chamber with water, use of wetting agents, etc., are examples of techniques to remove air from the test specimen. The ports shall also be located in such a manner as to allow removal of the water from the specimen for subsequent internal gas tests.

5.8.1.5 Setup for TS-A

An example setup for TS-A is shown in Figure 14. The port identified as key item 3 in Figure 14 shall be at the top of the external pressure chamber during setup and stabilization to remove air from the chamber. Then rotate the assembly around its longitudinal axis so that this port is as close as possible to 20° off vertical for leak detection or connect the leak detection hose to alternative port location, for example bottom (180°) or side (90°) of the chamber, to prevent any remaining air from entering the leak detection tube. The port identified as key item 11 in Figure 14 shall line up with the test specimen internal diameter or below.

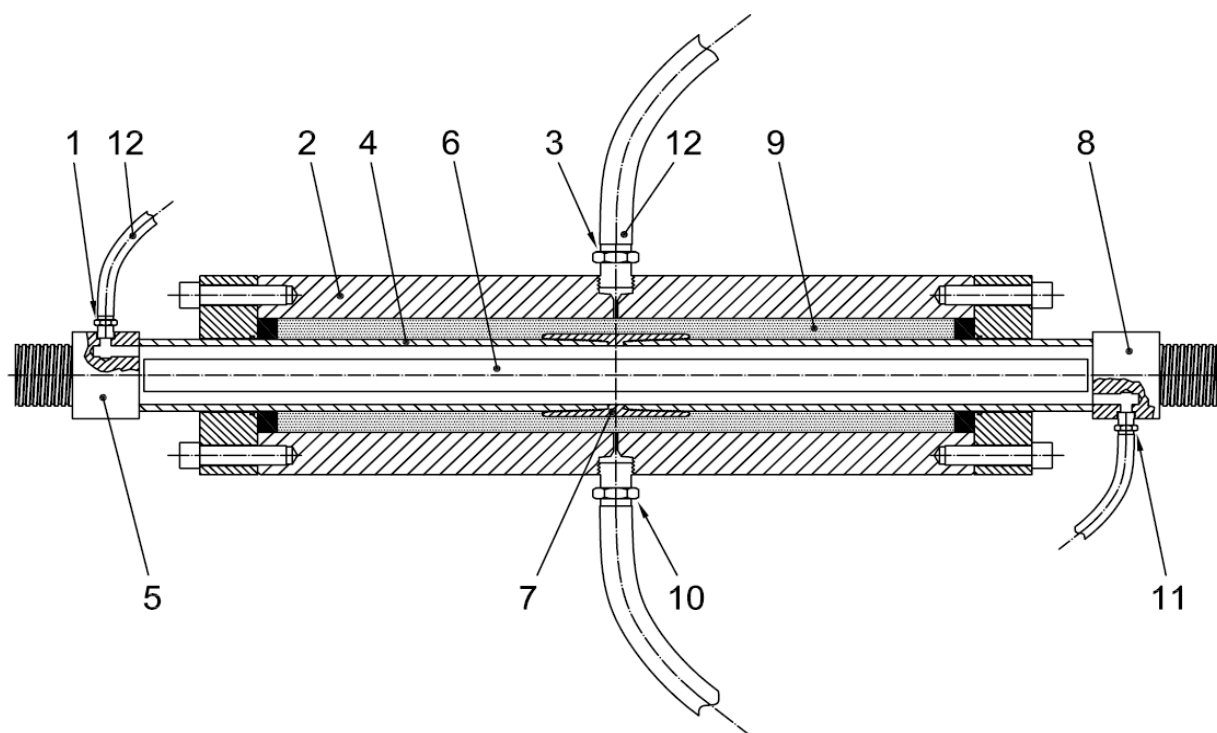
5.8.1.6 Leak Detection and Measurement by Water Level

For internal pressure tests at ambient temperature, the chamber and leak detection lines shall be filled with water as described in 5.8.1.4. As described in 5.8.1.5, the flexible hose shall be connected to the leak detection system as shown in key items 3 and 12 in Figure 14 and item 8 in Figure 15.

For external pressure tests at ambient temperature, the specimen and leak detection lines shall be filled with water as described in 5.8.1.4. As described in 5.8.1.5, the flexible hose shall be connected to the leak detection system as shown in key items 8 and 12 in Figure 14 and item 8 in Figure 15.

During TS-A pressure testing, a chamber encloses the test connection and some portion of the pipe on both sides of the connection. During the pressure testing, it has been observed that immediately after reaching full pressure and axial load, there may be significant (greater than 0.9 cm³/15 minute) water displacement. This displacement usually exhibits a decreasing trend that requires a stabilization period that shall be performed before starting the required hold period. In view of this test behavior, the following criteria should be used for TS-A pressure tests.

- a) Apply the full required internal or external test pressure and close the pressure line valves from the pressurizing pump.
- b) Small pressure increases may be necessary immediately after closing the valves in order to maintain the required pressure.
- c) Begin recording the frame loads, pressures, and graduated cylinder water level readings shortly after closing the valves (after target loads are applied and the leak detection system is stabilized).
- d) Record the frame loads, pressures, and graduated cylinder water level readings as described in 8.3.
- e) Document the leak rate and note the trend of leakage in the bubble tube—pressure sealing acceptance criteria are stated in 8.3.



Key

- | | | | |
|---|---|----|--|
| 1 | port for pressure transducer for internal gas test, leak detection for external pressure test, shop air inlet to drain water after external pressure test | 7 | test connection |
| 2 | external pressure chamber | 8 | end cap containing bottom internal port, see key item 11 |
| 3 | hole, equipped with flexible hose to leak detection for internal pressure test or pressure transducer for external pressure test | 9 | chamber, fully filled with water |
| 4 | test pipe | 10 | hole, for water pressure inlet to chamber |
| 5 | end cap, containing top internal port, see key item 1 | 11 | port for gas pressure inlet, water fill for external pressure test, water drain after external pressure test |
| 6 | internal filler bar, for safety | 12 | flexible hose that attaches to leak detection system (see key item 8 in Figure 15) |

Figure 14—Example Setup for TS-A

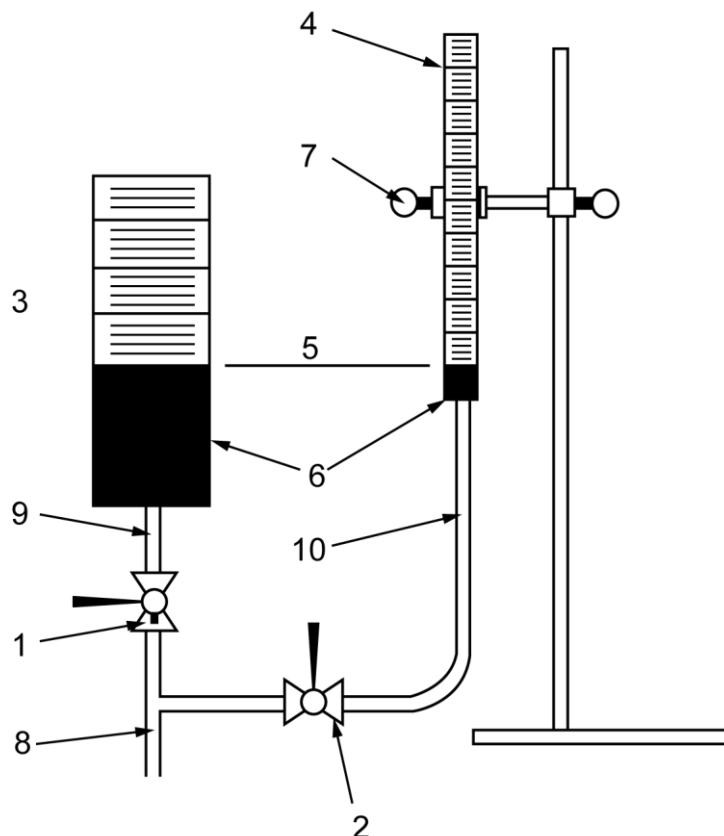
For both internal and external tests, at the start of the test, the large graduated cylinder shown in Figure 15 is approximately half filled with fluid. Before test loads are applied and adjusted, the large valve (see key item 1 in Figure 15) is opened and the small valve (see key item 2 in Figure 15) is closed. The fluid level inside the large cylinder will rise or fall with the applied test loads. At the start of a hold period, the small valve (see key item 2 in Figure 15) is opened and the position of the small graduated cylinder is adjusted up or down so that the fluid level in the small cylinder is near the bottom of the cylinder. The large valve (see key item 1 in Figure 15) is then closed. If a connection leak occurs, the fluid level in the small cylinder will rise and can be observed and measured in time to give a leak rate. A coloring agent should be added to the fluid inside the cylinders for ease of viewing the water level.

The fluid level in the small cylinder shall be recorded at the start and end of each hold period and at the intervals stated in 8.3.2 when a connection leak occurs to determine the leak characteristic.

5.8.2 Tests Performed at Elevated Temperature

5.8.2.1 Principle

Due to the difficulty of performing external pressure tests at elevated temperature with an accurate leak detection system, the principle is to exercise the connection at elevated temperature and the leak detection system is used to detect connection leaks for information purposes only.



Key

- 1 valve to large graduated cylinder
- 2 valve to small graduated cylinder
- 3 large graduated cylinder with open top (approximately 100 cm³ to 200 cm³)
- 4 small graduated cylinder with 0.1 cm³ graduations with open top (approximately 25 cm³)
- 5 water level
- 6 colored water
- 7 adjustable cylinder support to allow bottom of cylinder to be located at 100 cm³ to 200 cm³ water level at start of each hold period
- 8 flexible hose attached to top of chamber for internal gas tests and top port at one of end caps for external tests
- 9 flexible hose to large cylinder
- 10 flexible hose to small cylinder

Figure 15—Example of Leak Detection System for TS-A with External Pressure Chamber on Specimen for Ambient Internal and External Pressure Testing

Caution—The setup in Figure 15 should not be used for elevated temperature testing.

TS-A leak detection at elevated temperature shall be performed by pressure drop method. If the external pressure vessel is removed, internal pressure at elevated temperature shall be performed in accordance with 5.7. Leaks, regardless of detection method (pressure, volume, or rate), shall be reported.

For the TS-A elevated temperature testing, the requirements in 5.10 apply.

5.8.2.2 Pressurization Media

Internal pressure testing shall be conducted with dry nitrogen. External pressure tests shall be conducted with an appropriate liquid that remains in a liquid state at a temperature above the test temperature.