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Qualification of casing connections for thermal wells

Qualification des raccordements de boîtiers pour les puits thermiques

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

The committee responsible for this document is ISO/TC 67, *Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries*, Subcommittee SC 5, *Casing, tubing and drill pipe*.

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Introduction

This Thermal Well Casing Connection Evaluation Protocol (TWCCEP) provides procedures for assessment and thereby enables evaluation of suitability of threaded casing connections for service in intermediate or production casing strings of thermal recovery wells. The TWCCEP defines such wells as those with operating temperatures that cyclically vary between minimum values appreciably below 180°C and maximum values that range from 180°C to 350°C, in which the casing string is cemented and the primary axial loading is strain-based.

Throughout this document, a casing connection subject to evaluation is referred to as candidate connection. A candidate connection denotes a product with unique design features and production specifications for size, weight, and component materials (including pin, box, and interfacial components).

The TWCCEP assesses the candidate connection's galling resistance, structural integrity and sealability under loads typical for connection assembly and thermal-well service. The TWCCEP does not address impacts of external pressure, incomplete lateral pipe support, rotational fatigue, formation-induced shear, or environmentally-induced corrosion or cracking.

The TWCCEP's evaluation procedure includes analysis and full-scale testing. In the analysis, worst-case combinations of the connection geometry and material properties are determined and specifications for test specimens are derived. In the full-scale tests, those specimens are subjected to loading representative of thermal well operations. While the TWCCEP aims to enable a statistically significant full-scale test, it does not demand a rigorous check of a true statistical placement of the tested sample responses relative to field connection performance, and thus inherently assumes that the test specimens are representative of subsequent field connections. For this reason, only connections with the same design parameters as the candidate connection should be considered representative of the connection assessed under this protocol.

The extensive effort involved in replicating thermal well field conditions in a laboratory environment limits the extent of physical testing that can reasonably be undertaken in an evaluation program. This protocol balances technical rigor and practicality to provide a baseline level of confidence in the candidate connection's performance. Connection users should consider the scope of this evaluation and appropriate additions to address operation-specific conditions. Successful field use of a connection meeting the requirements of this protocol does not preclude an operator's need to employ appropriate product quality assurance measures and field operating practices.

The TWCCEP is the culmination of a thorough review of factors contributing to performance of casing connections in thermal well applications. This protocol has been developed using input from operators' descriptions of field practices, manufacturers' feedback on connection design and production, available literature, knowledge of past connection qualification programs, and additional analytical and experimental work performed in support of the protocol development. The TWCCEP is intended to be maintained and refined as new findings surface.

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Qualification of casing connections for thermal wells

1 Scope

ISO/PAS 12835 is intended for assessment of casing connections for those field applications in which the design of the casing-connection system is strain-based, and in which primary axial loading is on the casing-connection system driven by constrained thermal expansion, and in which that primary loading exceeds the casing-connection system's yield envelope. Consequently, ISO/PAS 12835 should be considered as a protocol that is complementary to ISO 13679, which applies to classic elastic-design applications.

ISO/PAS 12835 describes the structure of the Thermal Well Casing Connection Evaluation Protocol (TWCCEP) and provides guidelines for its use by new or repeat TWCCEP users, whose familiarity with the TWCCEP provisions might vary. Clause 6 describes fundamental assumptions adopted in the TWCCEP.

NOTE The term "user" refers to a party that uses the TWCCEP in a connection evaluation program. That party might or might not be the same party as a later user of the evaluated connection in a field application.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the cited edition applies. For undated references, the latest editions of the reference documents apply.

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

ASTM E8, *Standard Test Methods for Tension Testing of Metallic Materials*

ASTM E21, *Standard Test Methods for Elevated-Temperature Tension Tests of Metallic Materials*

ASTM E831-06, *Linear Thermal Expansion of Solid Materials by Thermomechanical Analysis*

ISO 9001, *Quality management systems — Requirements*

ISO 11960, *Petroleum and natural gas industries — Steel pipe for use as casing and tubing for wells*[1)]

ISO 13679:2002, *Petroleum and natural gas industries — Procedures for testing casing and tubing connections*[2)]

3 Terms and definitions

For the purpose of this document, the following terms and definitions apply.

3.1
ambient temperature
ambient temperature in the facility where a physical testing task is executed

1) Based on API Specification 5CT.

2) Based on API Specification 5C5.

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3.2
application severity level
connection loading specifications assumed to be representative for a range of operational conditions, which determine the scope of analysis and testing required by the evaluation procedure (3.15) for those operational conditions

3.3
assigner
party that commissions an evaluation program (3.16)

3.4
average string strain
average axial strain along the controlled elongation interval (3.13) of a specimen string (3.37)

3.5
bend test specimens
subset of candidate connection specimens (3.8) subjected to the optional bending evaluation (3.6) per the TWCCEP evaluation procedure (3.15)

3.6
bending evaluation
analysis and physical testing conducted to determine a candidate connection's (3.7) sensitivity to casing curvature

3.7
candidate connection
casing connection product that is being evaluated by the TWCCEP, and is uniquely defined by its design features and production specifications with respect to size, weight, and component materials

3.8
candidate connection specimens
a set of connection specimens (3.11, 3.12) that is representative of a candidate connection's (3.7) design and features, and is provided for an evaluation program (3.15) of that candidate connection (3.7)

3.9
casing pup
short piece of casing pipe cut from a mother joint

3.10
connection
single design-specific assembly of pin and box and interfacial component(s)

3.11
connection specimen (for threaded and coupled connections)
two connections consisting of a single coupling and two casing pups (3.9) with pin ends joined by that coupling

3.12
connection specimen (for integral connections)
one connection consisting of one casing pup (3.9) with a box end and one casing pup (3.9) with a pin end

3.13
controlled elongation interval
portion of a specimen string (3.37), along which the elongation is measured and controlled

3.14
effective string length
portion of the total length of a specimen string (3.37) that is assumed to deform appreciably under mechanical forces in the thermal cycle test (3.44)

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3.15
evaluation procedure
set of analytical and testing tasks required by the TWCCEP to assess performance of the candidate connection specimens (3.8)

3.16
evaluation program
execution of the TWCCEP to assess performance of a candidate connection (3.7)

3.17
evaluation report
collectively, all documents prepared by an evaluator (3.18), according to applicable TWCCEP reporting requirements, that describe an evaluation program's (3.16) execution history and results

3.18
evaluator
party that performs analytical and testing tasks required by an evaluation procedure (3.15)

3.19
excluded connection
connection (3.10) that has been evaluated in a TWCCEP full-scale test but whose performance has been excluded from comparison with threshold performance requirements (3.45)

3.20
galling
cold welding of contacting material surfaces followed by tearing of metal during subsequent sliding

3.21
high cycle temperature
targeted highest temperature in the thermal cycle test (3.44)

3.22
inspection report
collectively, all documents prepared by an inspector (3.23), according to applicable TWCCEP reporting requirements, that describe compliance of the executed evaluation program (3.16) with TWCCEP requirements

3.23
inspector
party that verifies compliance of the executed evaluation program (3.16) with requirements of the TWCCEP

3.24
interfacial component(s)
design-specific component(s) of a connection (3.10) applied to the pin and box either during their manufacturing (e.g. coatings) or during the connection assembly (e.g. thread compound)

3.25
limit-strain specimens
subset of candidate connection specimens (3.8) subjected to the limit-strain test (3.26) per the TWCCEP evaluation procedure (3.15)

3.26
limit-strain test
tension test, to structural failure, of the limit-strain specimens (3.25)

3.27
low cycle temperature
targeted lowest temperature in the thermal cycle test (3.44)

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3.28
make-break specimens
subset of candidate connection specimens (3.8) subjected to multiple make-ups and break-outs per the TWCCEP evaluation procedure (3.15)

3.29
make-up support pin
pin component of candidate connection (3.7) with seal removed, used to support a coupling's open end during make-up and break-out of that coupling's opposite end

3.30
material coupon
cylindrical section of pipe from which material strip specimens (3.31) are cut

3.31
material strip specimen
longitudinal steel strip cut from a material coupon (3.30) and machined for use in mechanical property characterization tests

3.32
prior evaluation data
set of data acquired in a connection performance assessment carried out by analysis and/or physical tests prior to issuance of this protocol and/or according to a procedure/protocol different than the TWCCEP evaluation procedure (3.15)

3.33
program roles
collective reference to the roles of assigner (3.3), supplier (3.39), evaluator (3.18) and inspector (3.23)

3.34
repairable galling
galling that can be repaired according to a supplier's (3.39) field-repair procedure for a candidate connection (3.7)

3.35
severe galling
galling that cannot be repaired according to a supplier's (3.39) field-repair procedure for a candidate connection (3.7)

3.36
specimen
used in commentary and/or descriptive context, denotes a generic reference to a connection specimen (3.11, 3.12) or to a material strip specimen (3.31)

3.37
specimen string
collective reference to a single connection specimen (3.11, 3.12) and/or an in-series assembly of two or more connection specimens (3.11, 3.12) in a thermal cycle test (3.44)

3.38
substantially qualified party
person/company possessing technical skills and experience necessary to perform a task, as designated by the assigner (3.3) and the supplier (3.39)

3.39
supplier
party that manufactures a candidate connection (3.7)

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3.40
tensile strain threshold
tensile strain value that a connection specimen (3.11, 3.12) is expected to survive during a limit-strain test (3.26)

3.41
test specimen
used in commentary and/or descriptive context, denotes a generic reference to a connection specimen (3.11, 3.12) that is provided for a full-scale test

3.42
thermal cycle
used in commentary and/or descriptive context, denotes a temperature excursion from a low initial temperature to a high maximum temperature and back to the low initial temperature

3.43
thermal cycle specimens
subset of candidate connection specimens (3.8) subjected to the thermal cycle test (3.44) per the TWCCEP evaluation procedure (3.15)

3.44
thermal cycle test
thermo-mechanical test of connection specimens (3.11, 3.12), in which several thermal cycles are applied between the low cycle temperature (3.27) and the high cycle temperature (3.21)

3.45
threshold performance requirements
set of connection performance criteria that candidate connection specimens (3.8) must satisfy in order for a candidate connection (3.7) to be considered as having met TWCCEP minimum performance requirements

4 Abbreviations, symbols and illustrations of selected definitions

4.1 Abbreviations

Terms defined in Table 1 denote abbreviations used for descriptive purposes.

Table 1 — List of abbreviations

ASL	application severity level
BF	fast box taper
BS	slow box taper
CSS	cyclic steam stimulation
CTE	coefficient of thermal expansion
FEA	finite element analysis
max.	maximum
min.	minimum
PF	fast pin taper
PS	slow pin taper
SAGD	steam assisted gravity drainage

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TC	threaded-and-coupled
TWCCEP	thermal well casing connection evaluation protocol
TF(WGS)	final make-up torque for specimen with WGS configuration
TF(WGT)	final make-up torque for specimen with WGT configuration
TF(WSC-M)	final make-up torque for specimen with WSC configuration and multiple make-ups
TF(WSC-S)	final make-up torque for specimen with WSC configuration and single make-up
TF(WST-M)	final make-up torque for specimen with WST configuration and multiple make-ups
TF(WST-S)	final make-up torque for specimen with WST configuration and single make-up
WGS	worst-case tolerance combination for galling in seal
WGT	worst-case tolerance combination for galling in threads
WSC	worst-case tolerance combination for sealability in compression at high temperature
WST	worst-case tolerance combination for sealability in tension at low temperature

4.2 Symbols

Terms defined in Table 2 denote variables, which depend on the selected application severity level (ASL) and other protocol options, procedural calculations, and interim results.

Table 2 — Symbols

CTE_a	average coefficient of thermal expansion
ρ_{MAX}	maximum test curvature
D	casing outside diameter
$\Delta\varepsilon_{LL}$	strain increment for application in the limit-strain test
$\Delta\rho$	curvature increment
$ETTE_a$	average residual post-cycle strain
L_{CEI}	length of controlled elongation interval
L_p	unsupported pup length (pup length excluding make-up loss, i.e. pin-box overlaps at each end)
$LTTS$	lower-bound temperature strain increment
$SLCF$	strain-length compensating factor
SRI	temperature range strain increment
$SSP(T)$	saturated steam pressure at temperature T
t	casing wall thickness
T	temperature
T_{amb}	ambient temperature
T_{hc}	high cycle temperature

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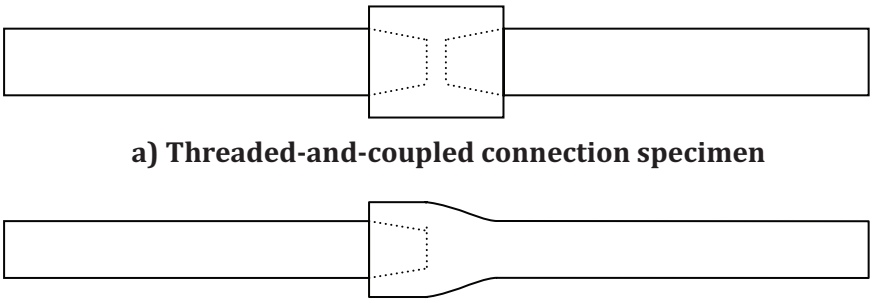
T_{lb} lower-bound temperature for a given application severity level

T_{lc} low cycle temperature

T_{ub} upper-bound temperature for a given application severity level

4.3 Illustrations of selected definitions

Figure 1 illustrates a connection specimen (3.11, 3.12). Figure 1 a) shows a connection specimen for a threaded-and-coupled (TC) connection (3.11), and Figure 1 b) shows a connection specimen for an integral connection (3.12). A threaded-and-coupled connection specimen consists of one coupling and two casing pups (3.9), and contains two connections (two leak paths). An integral connection specimen consists of one pin-end pup and one box-end pup, and contains one connection (one leak path).



a) Threaded-and-coupled connection specimen

b) Integral connection specimen

Figure 1 — Illustration of connection specimens

When full-scale testing is conducted on strings containing multiple connection specimens assembled in series, some casing pups are shared by two adjacent connection specimens (which might be either threaded and coupled or integral). Each such shared casing pup is considered to consist of two halves, with each half belonging to the connection specimen that includes the corresponding pin end or integral box end. Figure 2 illustrates an example of a string assembly with four connection specimens. For consistency with TWCCEP requirements for a thermal cycle test (3.44), in which a four-specimen string (3.37) assembly may be used, the example in Figure 2 shows Specimens 3, 4, 5, and 6. For threaded and coupled connection specimens, the two specimen leak paths can be distinguished by the specimen number and letters “A” and “B” referring to each specimen side.

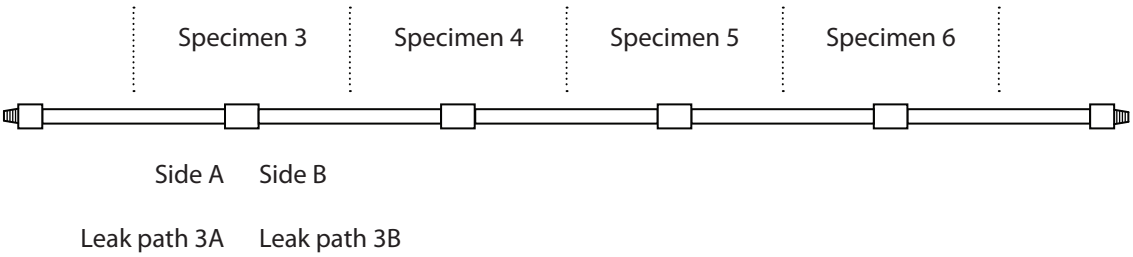


Figure 2 — Illustration of connection string assembly

5 Program flowchart

Figure 3 illustrates five main components (blocks) of a TWCCEP program (3.16). A detailed description of the TWCCEP blocks and tasks is provided in Clause 10.

General principles adopted for the TWCCEP evaluation procedure (3.15) are described in Clause 6. It is strongly recommended that all users of this document and all parties responsible for [illegible]

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of an assessed connection in a field application review Clause 6 and become aware of the assumption basis and procedural requirements specified by TWCCEP for the assessment tasks and data reporting.

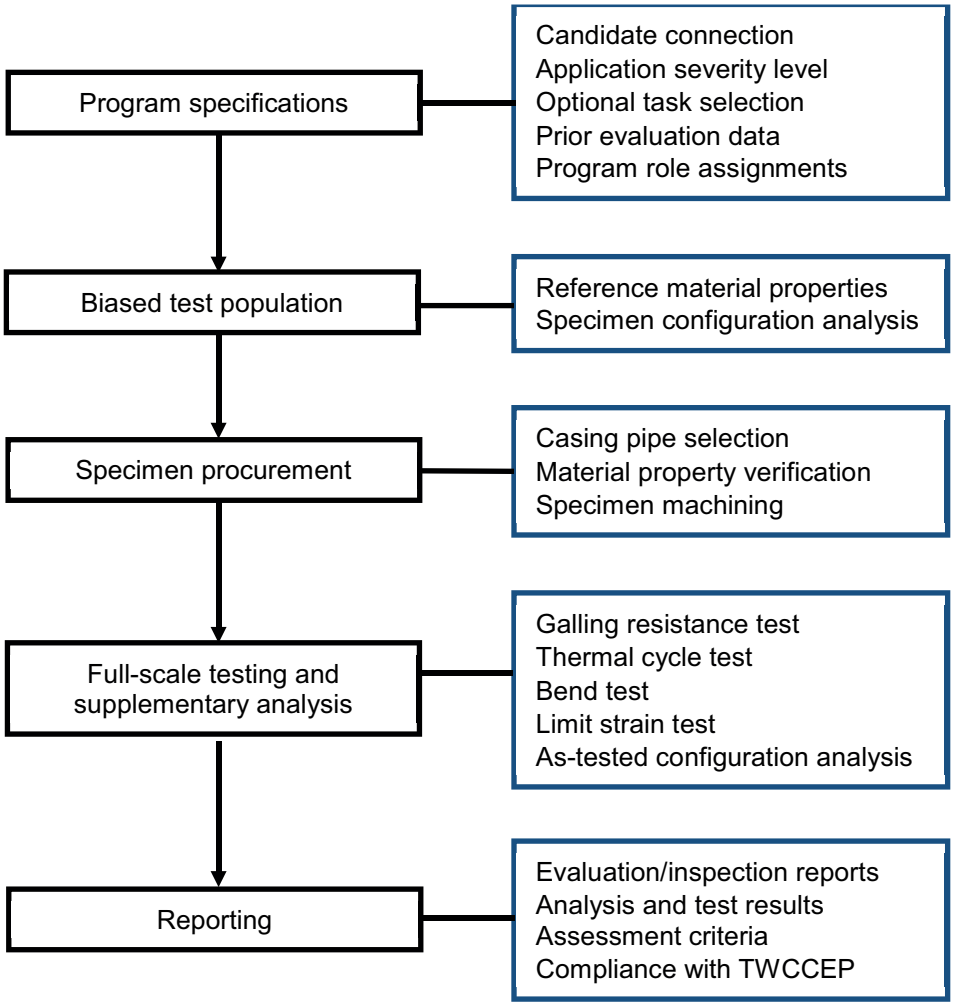

Figure 3 — TWCCEP flowchart

6 Overview and fundamental assumptions of TWCCEP

6.1 General

This Clause contains an overview of fundamental assumptions adopted for the TWCCEP, which are provided to facilitate understanding and interpretation of TWCCEP's provisions and procedural requirements specified in later Clauses of this document.

6.2 Main TWCCEP features

6.2.1 Purpose of TWCCEP

The TWCCEP provides procedures for assessing suitability of threaded casing connections for intermediate or production casing strings for thermal recovery wells. Conducting an assessment of a candidate connection according to the TWCCEP provides data that can be interpreted by a user to complete evaluation of the candidate connection.

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6.2.2 Applicability to service conditions

The TWCCEP applies to those field applications in which operational temperatures oscillate between a cold level, appreciably below 180°C, and a hot level, above 180°C, in which casing deformation is primarily driven by thermo-mechanical strain resulting from the above temperature excursions, and in which the casing body might or might not cyclically yield under the corresponding strain-driven loads.

Specifically, the TWCCEP applies to two thermal-recovery applications: Steam Assisted Gravity Drainage (SAGD) and Cyclic Steam Stimulation (CSS), in which thermal expansion of the casing string is constrained by cementing. The TWCCEP might also be used for qualifying connections for other extreme-service wells in which tubular undergo full-body yielding and for which deformation-tolerant design is desired; for example, wells in compacting reservoirs, steam-drive wells, geothermal wells, or some high-pressure, high-temperature wells.

6.2.3 Rationale for TWCCEP development

Lack of a standard connection evaluation procedure for thermal-well applications was the main rationale for developing the TWCCEP.

Loading of intermediate casing connections in thermally stimulated wells is very severe and of unique character. Prior to issuance of the TWCCEP, no other connection evaluation procedure had been adopted as an industry standard for those loading conditions. In particular, ISO 13679 provides procedures for evaluating casing and tubing connections only for elastic-design applications, in which the tubular-body stress state is assumed to remain elastic, and in which maximum operational temperatures do not generally exceed 180°C. Despite these fundamental differences, several similarities exist between the TWCCEP and ISO 13679. Where practical, such similarities are referred to in this document.

6.2.4 Subject of evaluation

A casing connection product subjected to an evaluation program is referred to as a candidate connection (3.7). A candidate connection denotes a product with unique design features and production specifications for size, weight, and component materials (including pin, box, and interfacial components (3.24)).

In general, one or more candidate connections can be assessed in an evaluation program. For simplicity, this document refers to a single candidate connection as a subject of evaluation. If two or more candidate connections are included in a single evaluation program, then all of the TWCCEP provisions apply to each candidate connection separately.

6.2.5 Application severity levels

The severity of field operating conditions varies. The TWCCEP distinguishes multiple ASLs, uniquely defined in terms of maximum operating temperature (see 9.3).

Temperature has been recognized as the primary variable influencing severity of pipe thermo-mechanical loading and the connection response to that loading, including sealability and structural performance. The following arguments support this assumption:

— constrained thermal expansion of cemented casing heated to the maximum operating temperature leads to pipe and/or connection yielding. The magnitude of the axial loads generated during heating (and also subsequent cooling during a well intervention), as well as the degree of post-yield deformation, strongly depend on the applied temperature range;

— in field service, applied internal pressures typically follow the saturated-steam relationship with temperature;

— properties of casing pipe and connection materials vary with temperature – the material yield strength typically decreases with temperature, and creep and relaxation effects become more pronounced at elevated temperatures;

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— elevated temperatures affect properties of thread compounds (dopes), and thus influence the role of the dope in premium seal activation. Such temperatures might also affect properties of some coatings used for dopeless connections. Higher temperatures are typically associated with faster degradation of dopes and coatings.

— the ASL is selected at the onset of each evaluation program. Some aspects of the TWCCEP evaluation procedure, such as severity of loading applied in numerical modelling and physical tests, depend on the selected ASL. TWCCEP assessment criteria are independent of the selected ASL.

6.3 Assessment philosophy and principles

6.3.1 Fundamental principles

The TWCCEP fundamental assessment philosophy is to:

— distinguish between those connection types that are suitable for thermal well service and those that are not;

— acquire key connection performance data for comparison with adopted minimum performance requirements, and also auxiliary performance data for determination of connection service boundaries;

— be practical to execute by analytical methods and laboratory testing.

Based on the above philosophy, the TWCCEP assumes the following principles for the evaluation basis:

Principle 1 The evaluation procedure should be conservative with respect to:

a) candidate connection samples: test specimen configurations should be chosen to have the least-favourable characteristics possible within production manufacturing ranges;

b) loading: evaluation procedure should employ the most severe loading that is representative of cited field conditions.

Principle 2 Given that field conditions vary, the evaluation procedure should provide options to tailor the evaluation scope to anticipated operational conditions.

Principle 3 The evaluation procedure should make the best use of available analytical and physical-testing tools.

Principle 4 The evaluation procedure should measure a candidate connection's performance with respect to those performance indicators that are considered critical for reliability in field service.

Principle 5 Assessment criteria should be chosen according to reasonable field-performance expectations. Assessment criteria should refer only to results of full-scale tests.

Principle 6 Where practical, auxiliary data should be collected to assess connection performance boundaries and safety margins with respect to cited service conditions.

Principle 7 Where possible and practical, data acquired in prior evaluations can be used, and the evaluation program scope can be reduced accordingly.

Principle 8 Execution of an evaluation program does not require the manufacturer of a candidate connection to reveal confidential connection design information beyond a level that enables third-party inspection.

Principle 9 Results of every evaluation program should be interpreted in the context of the completed evaluation scope and anticipated service conditions.

Principle 10 Perception of conflict of interest in executing an evaluation program should be avoided.

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Each principle listed above is further described in the following Clauses. Discussion of some principles is also illustrated by reference to Figure 6 and Table 5 in 10.1, which describe the tasks of the TWCCEP evaluation procedure.

6.3.2 Conservative evaluation procedure

The TWCCEP is based on the premise that the evaluation procedure should verify the adequacy of a candidate connection's performance under worst-case combinations of factors that affect its behaviour, including connection geometry, manufacturing tolerances, material properties, assembly, and operational loading. Principle 1 (6.3.1) is implemented by the following steps:

a) Determine the worst-case combinations of manufacturing and assembly variables for the candidate connection, and treat those combinations as specifications for a biased test population.

b) Evaluate the biased test population under the established representative loading.

c) Compare the measured performance of the biased test population to adopted performance requirements. Record acceptance if those requirements are met, or failure if those requirements are not met.

d) Assume that any production series of the candidate connection will perform equally well or better in relevant field service than the evaluated, biased test population.

Step a) above is referred to as the front-end determination of the biased test population. Steps b) and c) are performed in the evaluation program by full-scale testing and supplementary analyses. Step d) is executed based on the acquired evaluation results.

6.3.3 Mandatory and optional tasks

The TWCCEP evaluation procedure contains mandatory tasks and optional tasks, which allows the evaluation scope to be tailored to specific operational conditions (per Principle 2 in 6.3.1):

— mandatory tasks are considered critical for evaluation of connections for all applications to which the TWCCEP applies. Completion of all mandatory tasks is required in every evaluation program;

— optional tasks are those tasks that should be chosen so that the evaluation program provides results most relevant for the cited operational conditions. It is mandatory to consider all program options, consciously select an optional task scope suitable for each evaluation program, and then execute the selected options accordingly. It is not mandatory to execute those optional tasks that have not been selected.

TWCCEP mandatory and optional tasks are listed in Figure 6 and Table 5. Examples of optional tasks are: seal taper analysis, bending evaluation (3.6), and seepage measurement in the limit-strain test (3.26).

Since review of the optional task menu is mandatory, descriptions of all mandatory tasks and optional tasks are kept together in the main body of this document, so that the rationale for each option is presented in a logical order and subsequent selection decisions are facilitated.

In some optional tasks, the TWCCEP provides specific directions relative to the task scope and/or procedures. In other program options, the TWCCEP provides only general recommendations that the discussed issues should be addressed in the context of the intended application.

In some TWCCEP programs, a candidate connection might be evaluated at a time when future use of the connection is unknown. When the candidate connection is later contemplated for use in a specific application, the prospective user of the candidate connection should:

— carefully review the details of the executed evaluation program, including the selected program options;

— determine if the executed scope provides an adequate level of evaluation for the intended application;

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— if need be, consider executing additional evaluation tasks according to other program options that were not selected previously.

6.3.4 Use of analysis and physical testing

Per Principle 3 (6.3.1), the TWCCEP employs both analysis and physical testing. The overall scope of the prescribed analysis and physical-testing includes both mandatory and optional tasks, as described in Clause 6.3.3. Figure 6 summarizes all analytical and testing tasks of the TWCCEP evaluation procedure. Table 5 indicates the categories of data acquired in each task, as described in 6.3.7.

Analysis is an efficient and effective tool to examine connection sensitivity to design and operational variables. In general, an analytical task can involve a combination of engineering derivations based on closed-form solutions and numerical analysis based on the finite element method. Those formulations facilitate parametric studies, in which connection sensitivities might be readily assessed with respect to many – but not all – manufacturing and loading variables.

In the TWCCEP, analysis is employed to select the biased test population, guide subsequent program execution (see 6.3.2), and acquire auxiliary data on candidate connection performance boundaries (see 6.3.7). Some analytical results may also be used to specify additional testing to verify candidate connection performance under application-specific conditions that are not simulated in the mandatory tests. No analytical results are compared to TWCCEP threshold performance requirements (3.45).

Physical full-scale tests are considered to be all inclusive verification of connection performance, because they account for all design variables i.e. both the variables that are controlled in the connection manufacturing process and the "black-box" variables that are not explicitly controlled, such as pin and box waviness. In preparation of the test specimens (3.41), the black-box variables are assumed to be at values representative of production connections. It is recognized that this assumption might not always be conservative because the test samples are prepared according to custom specifications and manufactured outside of standard production runs. For example, the test specimens might have a higher degree of circumferential uniformity than production connections.

Results obtained in the physical testing fall into several categories (see 6.3.7). For example, some results from mandatory tests are key performance indicators. Those are the only results that are compared with TWCCEP performance requirements (see 6.3.5 and 6.3.6), to determine whether or not the candidate connection performance meets the requirements of this protocol. Other results from mandatory tests and all results from optional tests are considered to be auxiliary performance data.

6.3.5 Performance measures

The TWCCEP assesses the following connection performance measures:

— galling resistance;

— structural integrity;

— sealability.

The TWCCEP excludes assessment of a connection resistance to environmental corrosion and cracking.

The above choice of performance measures results from the TWCCEP's focus on connection response to assembly and thermo-mechanical loading. While environmentally-induced corrosion and cracking is a significant loading component active in thermal wells, those loading mechanisms are excluded from consideration in the TWCCEP evaluation until synergies between thermo-mechanical and environmental loading are better understood.

6.3.6 Assessment criteria

6.3.10 provides guidelines for interpreting results acquired in a TWCCEP evaluation program in the context of a specific field application. To facilitate this interpretation, the TWCCEP adopts reference performance requirements, which are referred to as threshold performance requirements (3.45). A

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candidate connection is considered to have met the performance requirements of this protocol if the candidate connection's performance meets or exceeds all applicable threshold performance requirements. Only results of full-scale tests are compared with the threshold performance requirements.

The following threshold performance requirements are adopted for the mandatory physical tests:

— no evidence of severe (irreparable) galling (3.20) in the galling resistance test;

— lack of structural failure in any combined-loading test;

— seepage rates below adopted threshold rates in sealability tests.

6.5.3 provides guidance for seepage threshold rates to be used in sealability tests.

The TWCCEP also recommends assessment criteria for the optional physical tests, which refer to structural strength and sealability. Use of those assessment criteria is optional at the assigner's (3.3) discretion. It can be expected that in some evaluation programs alternative assessment criteria for the optional tasks might be adopted by agreement between the assigner (3.3), the supplier (3.39) and the evaluator (3.18). The TWCCEP does not provide any provisions for such agreements, but requires that the agreed assessment criteria be documented in the evaluation report (3.17).

6.3.7 Task outcomes — data categories

In order to implement Principles 1, 4, and 6 (6.3.1), the TWCCEP recognizes the following categories of data acquired in various tasks:

— input for further tasks. This data type is acquired in tasks that determine the completion scope of subsequent tasks (e.g. determination of the biased test population);

— key performance measures. These results are compared with TWCCEP acceptance criteria to determine whether or not the candidate connection meets, or does not meet, the TWCCEP's threshold performance requirements;

— auxiliary performance data. These results also assess connection performance, but are not graded against any acceptance criteria.

Acquiring data in the first two categories is mandatory in all TWCCEP tasks. Acquiring data in the third category is mandatory in some tasks and optional in some other tasks (see Table 5). The TWCCEP recommends that auxiliary data should be collected whenever practical, because that data provides valuable information for prospective connection users. This recommendation is particularly relevant for new connection designs, or those connections for which little prior evaluation data (3.32) are available.

6.3.8 Prior evaluation data

Data acquired in a connection assessment program executed prior to a TWCCEP evaluation program, referred to as "Prior Evaluation Data," may be used in lieu of some or all analysis or testing required by the TWCCEP evaluation program if it is demonstrated that the scope, procedures, execution history, and documentation that were employed to acquire and record prior evaluation data, all meet or exceed the corresponding requirements of the TWCCEP (8.5).

The spirit of this provision is to enable use of complete or partial results from analysis and/or full-scale tests performed according to other proprietary or standard protocols. For example, historic evaluations performed by some operators in Alberta, Canada; or assessments performed in-house by connection suppliers; or from material characterization tests done on various OCTG tubulars.

6.3.9 Treatment of confidential design information

It is recognized that connection design information is proprietary by nature, and that connection manufacturers might not want to reveal some of that information, e.g. machining drawings, to any other party. The TWCCEP is structured so that it can be executed with or without exchange of candidate

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connection drawings among the parties involved in the evaluation tasks (see 7.2). The possible extent of third party inspection will be influenced by the extent to which the connection design information is revealed.

6.3.10 Interpretation of TWCCEP results

The TWCCEP does not provide a single pass-fail "certificate". Instead, the TWCCEP requires that a comprehensive evaluation report be prepared for each evaluation program, and that the report be available to a prospective user of the evaluated connection.

From the user perspective, meeting TWCCEP performance requirements should be considered as an indication of conformance to adopted performance standards. Those results should be interpreted with due consideration given to the scope of the completed evaluation program and prospective field-service requirements.

Since the TWCCEP cannot anticipate all facets of all field applications, the ultimate judgment on qualifying a connection for use in a given application rests with the connection user. The user must decide if results of an evaluation program indicate that the evaluated candidate connection is suitable for the intended application.

Having optional tasks in the TWCCEP structure, per Principle 2 (see 6.3.1), is desirable because it allows the TWCCEP procedure to be tailored to specific operational conditions and qualification requirements. As a consequence, comparing data from various programs demands a thorough review because selections of program options and optional tasks might vary. The demand for thoroughness is a positive consequence, because comparison of results among various TWCCEP programs should always be done consciously and cautiously.

6.3.11 Avoiding perception of conflict of interest

To benefit connection manufacturers and users, the TWCCEP specifies roles and responsibilities of various parties involved in the evaluation program so that the potential for perception of a conflict of interest is minimized. The party that commissions the evaluation program is referred to as the assigner; the party that manufactures a candidate connection is referred to as the supplier; the party that carries out the evaluation program is referred to as the evaluator; and the party that verifies compliance with this protocol is referred to as the inspector (3.23). At least two independent parties must be involved in all major evaluation tasks.

6.4 Evaluation variables

6.4.1 Connection loading

The TWCCEP evaluation procedure (including both mandatory and optional tasks) accounts for the following external loads:

— make-up torque;

— temperature;

— internal pressure;

— post-yield axial tension and compression generated by constrained thermal expansion;

— curvature-induced bending.

The TWCCEP does not address impacts of external pressure, fatigue, formation-induced shear (e.g. from geo-mechanical loads), cement voids or environmentally-induced corrosion or cracking.

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6.4.2 Impacts of contributing variables

As a consequence of Principle 1 (6.3.1), one of the main tasks in the TWCCEP development process was to assess impacts of design and loading variables contributing to connection performance in thermal well service. The first objective of the assessment was to distinguish between variables that exert major and minor impacts, so that the major-impact variables could be considered when selecting the worst-case variable combinations. The second objective was to distinguish "generic" variables, which could be assumed to have the same impacts on most premium connections, from "design-specific" variables, which might result in different performance trends in various connection types. The assessment results were used to develop TWCCEP criteria for selecting the biased connection test population and evaluation load cases.

Engineering analysis, numerical modelling, and reduced-scale testing were employed in the variable-impact assessment. Multiple reference configurations were considered for some variables, because sensitivities with respect to any individual variable might vary for different combinations of the other variables.

A variable was considered to have a major impact when variation of that variable within its production manufacturing tolerances or assembly targets or loading range caused a substantial change to a performance measure. Changes larger than 15 % relative to a value based on nominal conditions were typically considered to be substantial changes.

Following the impact assessment, the design and loading variables were categorized into five groups, as described in the following paragraphs.

Group 1: The first group consisted of the major-impact variables assumed common to most premium connection designs. Sensitivities to those variables were studied at the protocol development stage, and their worst-case combinations were established ("pre-set") for later use during protocol execution. For example, these investigations included determination of sensitivity of connection sealability to "bake-out" at maximum operating temperature so that sufficient specimen bake-out duration and loading (free versus constrained bake-out) could be specified for the protocol.

Group 2: The second group of variables included those major-impact variables for which different connection types could be expected to display different sensitivity trends. Given the potential for such connection-specific response, the TWCCEP includes a front-end assessment of the sensitivity trends with respect to the variables in that group, so that connection-specific choices of the test specimen configuration can be made for each evaluated connection. For example, yield strength of the connection pin material can have a strong impact on the seal contact stress depending on the connection material grade and range of property variations allowed for a given connection. The TWCCEP requires examination of those impacts for each candidate connection before selecting material specifications for test samples.

Group 3: Variables in the third group were of similar characteristics as in the second group (i.e. having major impact and being design-specific), with a distinction in that inclusion of the third-group variables in the selection of the biased test population was considered impractical because of challenges associated with conducting analysis or controlling those variables in the manufacturing process (e.g. seal tapers). The TWCCEP recommends optional-task evaluations of connection performance with respect to the variables in this group.

Group 4: The fourth group was chosen to include variables of similar characteristics as the second and third groups (i.e. having major impact and being design-specific), except that the variables in the fourth group were considered to have those characteristics only in some applications and not in other applications (e.g. severe curvature loading). Similar to the third group, the TWCCEP recommends optional-task evaluations of connection performance with respect to the variables in the fourth group.

Group 5: the fifth group of design and loading variables included those variables that were not considered significant for specifying procedures for the connection performance assessment. For example, some threadform details such as flank angles do affect connection load transfer, but variations of those variables within their manufacturing tolerances do not significantly change

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connection galling resistance, structural strength or sealability. The TWCCEP assumes nominal values for the variables in this group.

6.4.3 Pin-box interferences and tapers

Unless otherwise agreed by the assigner and the supplier, the following definitions shall be adopted:

— Diametric seal interference between the pin and box components of a candidate connection is the interference between the pin outside diameter and the box inside diameter at a reference seal location consistent with design and gauging practice for the candidate connection.

— Diametric thread interference between the pin and box components of a candidate connection is the interference between the pin and box pitch diameters at a reference thread location consistent with design and gauging practice for the candidate connection.

— For seals cut on conical surfaces, a seal taper is the change of seal diameter over a reference axial distance.

— For threads cut on conical surfaces, a thread taper is the change of thread pitch diameter over a reference axial distance.

For some connection designs, load transfer mode in the threads and manufacturing tolerances on thread forms will significantly impact diametral interferences. These impacts should be considered in the selection of minimum and maximum interference configurations for the biased test population (12.3.4) and test specimen specifications (13.4.6).

6.4.4 Material yield strength

Yield strengths and post-yield stiffnesses of connection component materials affect connection response to loading beyond the elastic limit. In general, two types of post-yield response are expected in a connection subjected to typical thermal-well loading:

— localized yielding due to stress-strain concentrations, for example, in thread roots or high-contact stress seal band;

— global yielding due to large mechanical strains generated by constrained thermal expansion, for example, in the pipe body and a connection's critical cross-sections.

The following assumptions are adopted:

— For most connection designs, the box component is appreciably stiffer than the pin component, and thus yield strength of the box material may be excluded from determination of the biased test population. Consideration of the box yield strength is an optional task;

— Yield strength of the pin material was found to have a major impact on the seal contact stress intensity, and is included as a mandatory task in determination of the biased test population for sealability tests;

— Material yield strength is not explicitly considered in specifying the test specimens for galling resistance tests. Manufacturing of the galling test specimens is guided by material selection based on sealability considerations;

— Impacts of pin and box material yield strength variations (within the candidate connection's manufacturing specifications) on localized yielding in thread roots is not explicitly addressed in selecting the biased test population. Those localized-yielding variations are assumed to not have a significant effect on the candidate connection's structural strength, which is assessed in the TWCCEP's full-scale tests.

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6.5 Evaluation procedure

6.5.1 Safety standards

All activities required or recommended by a TWCCEP evaluation procedure should be conducted to appropriate safety standards, in accordance with safety requirements and policies in place in the facilities conducting those activities. No TWCCEP provision shall be considered as a basis for overriding any applicable safety requirements.

6.5.2 Seepage assessment — Random variations

Connection sealability performance might vary considerably even for connection samples that have been manufactured and assembled according to identical specifications. In particular, variable seepage rates can be expected in physical tests involving elevated temperatures. Such "random" behaviour can result from degradation of thread compound at high temperatures (dope bake-off), movement of dope solid particles (e.g. as dependent on pin and box surface finish, dope density variations, time), variations of connection geometry not fully controlled in the manufacturing process (e.g. waviness), and other variables.

Statistical variations in seepage response typically increase with temperature. Some historic evaluations for high-temperature applications (e.g. CSS) addressed this statistical variation by requiring testing of multiple specimens of the same configuration. While there is insufficient data to support a rigorous statistical analysis of how many specimens are required to provide a representative connection population, four specimens have been used as a reasonable compromise between practicality and statistical considerations.

The TWCCEP requires four specimens in the thermal cycle test (4.3 illustrates connection specimen definitions for various connection types). Two of those specimens are manufactured according to the worst-case tolerance combination for sealability at the maximum test temperature, and the other two are manufactured according to the worst-case tolerance combination for sealability at the minimum test temperature after one thermal cycle. If those tolerance combinations are found to be the same for the minimum and maximum temperature, then four specimens of the same target configuration are tested.

6.5.3 Seepage rate thresholds

Tolerance for seepage in field application varies, because it depends on the well configuration, properties of the surrounding formation, well location, environmental considerations, and other factors. Based on the current state of industry knowledge, no practical "universal" threshold can be selected to suit all field applications.

For reference purposes, TWCCEP adopts three seepage thresholds:

— 0.06 mL/min = reportable seepage rate threshold. Any seepage activity observed in any sealability test that is larger than this level must be reported by the evaluator. This threshold is consistent with ISO 13679 standard;

— 1 mL/min = maximum seepage rate in axisymmetric compression. This threshold is consistent with some historic evaluations performed for CSS applications;

— 10 mL/min = maximum seepage rate in axisymmetric tension and under non-axisymmetric bending. For the axisymmetric tension, this threshold is consistent with some historic evaluations performed for CSS applications.

In combined loading cases involving axial forces and lateral loading, different combinations of external loading will result in varying the stress distribution around the connection circumference. Contact stress intensity in the connection seal can also be expected to vary around the circumference. Nonetheless, a single threshold of 10 mL/min has been adopted for simplicity.

It is understood that the original selection of seepage threshold rates in the historic evaluations referred to above was based on prior investigations that had been conducted on several 178 mm (7 in) casing

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connections, with no scaling for other connection sizes. Some connection users might find it justified, for their specific field applications, to adopt seepage thresholds different from the ones listed above. For example, a user might find it justified to scale the above historic seepage thresholds (1 mL/min and 10 mL/min) from the 177.8 mm (7 in) casing size by the ratio of the candidate connection size to the 177.8 mm size. If any threshold modifications are done within a specific TWCCEP evaluation program, the responsibility for any such threshold modifications rests with the assigner.

TWCCEP requires that:

— seepage rates be measured for individual connections (one side of a connection specimen for coupled connections, or one integral connection);

— the adopted seepage rate thresholds be documented and be applied to each individual connection (not to each connection specimen unless it is an integral connection, and not to strings with multiple specimens);

— measured seepage rates be reported for each event in which the measured seepage rate exceeds the reportable seepage rate threshold.

The reportable seepage rate threshold applies to each load step that contains a hold in any physical test. Each specified maximum seepage rate threshold applies to an average seepage rate calculated for holds at the same loading targets in all loading cycles (e.g. all high-temperature holds in the thermal cycle test), as described in 14.2.4.3.

It is recommended that other average and mean seepage rates (for the entire tested population) be calculated for information purposes.

6.5.4 Seal isolation

Sealability checks are conducted on primary connection seals that are isolated from any additional sealing mechanisms that might be active in the connection specimens. As a consequence, seepage detection ports need to be drilled into dope relief grooves, so that seepage across the primary radial seal is observed independently of any seepage blockage that might occur in the threads (14.2.4).

As another consequence, torque shoulder seals need to be disabled unless those are the primary sealing surfaces. If torque shoulders are the primary sealing surfaces, any other sealing surfaces that might impede gas flow to the seepage detection ports must be disabled (see 14.2.3).

It is acknowledged that drilling of the detection ports into the connection dope relief grooves, and in some cases also disabling of the torques shoulder seals, might lead to relieving of the dope entrapment (see 6.5.5) in a manner that is different from the field conditions.

6.5.5 Dope entrapment

Dope entrapment upon make-up can lead to deformation of the pin seal surface that exceeds the design intent, which might be detrimental to the connection sealability. For example, excessive axisymmetric deformation can lead to global reduction in the contact stress intensity. Alternatively, a circumferential buckling mechanism can cause the pin seal to become non-round (i.e. increase the pin waviness). Consequently, the seal contact stress distribution will be non-uniform, and seal burnishing might be inadequate.

Dope entrapment is more likely to occur when the amount of the dope applied prior to make-up is increased, and, to a lesser extent, when the makeup speed is increased. In a conservative sealability test, the largest amounts of dope allowed by the connection manufacturer should be applied to the test specimens. The specimen make-ups should be performed at maximum allowable speeds.

6.5.6 Thermal cycle test — Pre-test bake-out and hold durations

Each thermal cycle includes holds at maximum cycle temperature and at minimum cycle temperature. The duration of those holds should be long enough to capture time-sensitive impacts on the connection

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behaviour, yet as short as possible to minimize the test duration (cost). The major time-dependent factors are: behaviour of the seal components (changes in dope phases, movement of solid particles), and stress relaxation of pin and box materials (impact of multi-axial relaxation on radial contact stress).

It is assumed that a "sufficiently" long bake-out of the test specimens in the sealability test will adequately simulate the time-dependent dope degradation that occurs in field service, and its impact on sealability. The bake-out should be done with external loading, so that the loading conditions are consistent with the field service, where the connections are in axial compression during heating and subsequent hold at elevated temperature.

TWCCEP specifies the bake-out duration to be 120 h (see 14.4.7.2). Regarding dope degradation, it is assumed that once this bake-out is performed, no additional prolonged bake-outs are required at each high-temperature hold.

For typical OCTG materials, stress relaxation effects follow an exponential-decay with time. The relaxation is more pronounced in the initial portion of any hold than in the later stages of that hold. Stress relaxation strongly depends on temperature – it is higher at elevated temperatures than at room temperature. Stress relaxation also depends on applied stress and strain, with the amount of relaxation typically increasing with the stress-strain magnitude (although that relationship is expected to be material-specific).

Engineering experience indicates that the majority of stress relaxation occurs within 24 to 48 h, when high-temperature strain is held constant. The adopted bake-out duration is thus adequate for relaxation to be nearly exhausted in the first thermal cycle. Relaxation is small during low-temperature holds, so that subsequent 4 h high-temperature holds are long enough to counteract low-temperature relaxation.

Any pre-test exposure of the test specimens to elevated temperatures should be carefully considered, to avoid any significant changes of the specimen material properties that would be inconsistent with the operational loading scenario.

6.5.7 Pressure and temperature loading in thermal cycle test and analysis

TWCCEP's loading procedure for the thermal cycle test (see 14.4.7) is based on the assumption that in thermal operations internal casing pressure closely follows the saturated-steam relationship with temperature, although the sequence of pressure and temperature changes in field operations might not exactly correspond to the saturated-steam relationship. For example, casing temperature typically lags casing pressure during the heating part of a thermal cycle, due to delays caused by finite heat transfer rates. In the cooling part of a cycle, temperature can decrease while well pressure is maintained by ingress of reservoir fluids. The departures of the pressure-temperature loading sequence from the saturated-steam relationship will vary for different field operations, and thus would be challenging to quantify and/or specify for general evaluation purposes. Those loading-sequence differences are considered to have little impact on connection performance during the test holds under full pressure and extreme temperature. For that reason, and also for practical test-control considerations, those differences are disregarded in the thermal cycle test procedure.

TWCCEP's modelling guidelines (see Annex A) specify a load path in which pressure changes precede temperature changes in a simulated thermal cycle. In some supplementary numerical evaluations and parametric studies conducted on a generic connection model in support of the TWCCEP development, that load path was found to be somewhat more severe than simultaneous application of the pressure and temperature-driven loads. Subsequently, that sequence was chosen for the TWCCEP's numerical evaluation tasks associated with selection of the biased test population. The resultant discrepancy between the loading sequence in the analysis and physical test is believed to be not significant for connection evaluation purposes.

6.5.8 Dependence of material strength on temperature

The TWCCEP assumes consistency of material-strength dependency on temperature. For a given production material, proportional reduction of yield strength at any given elevated temperature is

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assumed to be the same for samples of that material coming from the lower end and from the higher end of the allowable range of the production yield strength.

While it is recognized that material temperature-dependence is typically not controlled in pipe production, the TWCCEP developers will welcome any data that might confirm or refute this assumption in future editions.

6.6 Scope of reporting

The TWCCEP requires that a comprehensive evaluation report be issued upon completion of each evaluation program. The evaluation report is required to contain a description of the assumed program roles (3.33), details of the candidate connection, all data acquired in the analysis and physical testing, comparison of the results with threshold performance requirements, and any non-compliances with respect to the TWCCEP evaluation procedure.

The requirement for the evaluation report to contain all data acquired in the analysis and physical testing will enable a thorough assessment of the candidate connection performance, not only at the time when the evaluation program is completed but also at later occasions. Such a future assessment might be conducted by a party that was or was not involved in the original evaluation. It might also be performed for an application that might be similar or different from the application targeted in the original evaluation. In the opinion of the TWCCEP developers, design engineers working on such future projects will benefit more from knowledge of the connection response to each loading step in the evaluation procedure than from comparison of the selected performance indicators to arbitrary threshold requirements. Therefore, the Evaluation Report is intended to provide a complete record of the executed evaluation program.

7 Program roles and proprietary design information

7.1 Program execution roles

It is anticipated that the TWCCEP will be executed in different types of connection evaluation programs – some commissioned by users (operators), some by connection manufacturers, and some by groups involving various companies. In order to facilitate definition and interpretation of the evaluation procedure (3.15) the TWCCEP defines the following program roles:

Assigner: the party that commissions an evaluation program, controls its execution, and owns the rights to an evaluation program's data and results.

Supplier: the party that manufactures a candidate connection.

Evaluator: the party that performs analysis and testing specified by an evaluation procedure.

Inspector: the party that verifies compliance of the evaluation program execution with TWCCEP requirements.

Annex C provides recommendations for role assignments, responsibilities and combinations in which single/multiple parties can assume single/multiple program roles.

7.2 Proprietary connection design information

It is recognized that connection design information is proprietary by nature, and that a supplier might not want to reveal some of that information, e.g. machining drawings, to any other party. The TWCCEP is structured so that it can be executed with or without exchange of candidate connection drawings among the parties involved in the evaluation tasks.

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The following principles are adopted by the TWCCEP for handling of proprietary/confidential information for the purpose of performing TWCCEP evaluation tasks:

— The TWCCEP does not require a supplier to provide candidate connection machining drawings to any other party within execution of an evaluation procedure.

— The TWCCEP does not require an evaluator to reveal any candidate connection machining drawing details in the evaluation report, except the information that is necessary to uniquely identify the candidate connection (e.g. the interfacial component has to be described with enough detail to allow unique identification of a product that has been tested in an evaluation program).

— At the onset of each evaluation program, the assigner and the supplier shall agree on the extent of exchange of proprietary information for the purpose of executing the evaluation procedure. If the assigner and the supplier are the same party, then that party alone decides on any such exchange.

— The evaluation report shall describe all role assignments, including selection of parties performing various evaluation tasks and their respective responsibilities, and the agreement between the assigner and the supplier relative to exchange of proprietary design information.

EXAMPLE Evaluation program conducted in-house by a supplier:

When an evaluation program is conducted in-house by a connection manufacturer, the manufacturer might simultaneously assume the roles of the assigner, the supplier, and the evaluator. The manufacturer will use the candidate connection drawings internally to build FEA models and perform Task 2.2 Specimen Configuration Analysis (see 12.3.1). The results will be included in the evaluation report, but possibly with no geometry details of the candidate connection. When those details are not revealed to the inspector, then the inspector will be able to review the analysis results but not the consistency of the FEA model with the connection's geometry.

8 Compliance requirements

8.1 Compliant evaluation program

An evaluation program shall be considered compliant with the requirements of this protocol if and only if either of the following two sets of conditions is satisfied:

— Set 1: The evaluation program was executed in full compliance with all clauses of the TWCCEP; and such fully compliant execution is documented as such by the evaluation report and the inspection report;

— Set 2: The evaluation program was executed in partial compliance with the clauses of this protocol; all non-conformances are described by the evaluation report and/or the inspection report, whichever is relevant; and each such non-conformance is accepted as not having substantially alleviated the requirements of this protocol and not having led to a substantial misrepresentation of the candidate connection's performance.

8.2 defines "non-conformance" and describes the process for accepting a non-conformance as satisfying the above Set 2 conditions.

8.2 Program non-conformances

In this protocol, a non-conformance occurs whenever one or more conditions of a mandatory provision are not satisfied (i.e. non-conformances apply only to "shall" clauses). In general, non-conformances might occur with respect to program roles, analysis or test procedures, or reporting.

The practicality of carrying out an evaluation program might sometimes suggest that non-conformances be accepted during the program execution (e.g. when a test specimen gets damaged and needs to be replaced by another specimen, and the available replacement specimen has a different loading history than the damaged specimen) or after the program execution (e.g. when data review indicates that a specimen temperature was outside the allowed range in a certain location). Acceptance of a non-conformance will be facilitated when the intended use of the evaluation program results is known at

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the time of the program execution, for example when a candidate connection is being evaluated for use in an existing operation with defined specific requirements. In other cases, acceptance of a non-conformance might be more difficult, for example when a candidate connection is evaluated for future applications with operational conditions unknown at the time of the evaluation program execution; or when a connection manufacturer evaluates a new connection for several prospective users/applications that might differ in non-conformance tolerance.

The following principles shall be observed in the process of accepting a non-conformance as not having substantially alleviated the requirements of this protocol and not having led to a substantial misrepresentation of a candidate connection's performance:

— at least two different parties performing the program roles shall assess the rationale and potential implications of the non-conformance, and agree on accepting the non-conformance;

— one of the parties mentioned above shall be the assigner. The other party shall be the first party that is different from the assigner in the following order: supplier, evaluator or inspector;

— all non-conformances shall be documented and the relevant documentation explaining the rationale for accepting each non-conformance shall be retained by the assigner as part of the evaluation report.

8.3 Performance acceptance

In any single evaluation program, a candidate connection shall be considered to have met the performance requirements of this protocol for the selected ASL if all of the following conditions are satisfied:

— the evaluation program has been compliant with the requirements of this protocol (according to criteria specified in 8.1);

— the candidate connection's performance, measured by the evaluation procedure, has met all applicable threshold performance requirements (only results of full-scale testing shall be considered in meeting the threshold performance requirements);

— execution and results of the evaluation program have been fully documented in an evaluation report and, as applicable, in an inspection report; and copies of the evaluation report and the inspection report have been delivered to the assigner.

8.4 Conformance of results from previous TWCCEP evaluations

Results of an evaluation program carried out in accordance with prior versions of the TWCCEP shall be considered representative of an evaluation carried out in accordance with the current version of the TWCCEP, provided that the candidate connection met threshold performance requirements applicable when the evaluation program was executed, and provided that the revisions between the prior TWCCEP version and the current TWCCEP version have not caused a substantial change in the evaluation procedure or the threshold performance requirements. If such a substantial change has been made and acknowledged in the TWCCEP revision summary, then the results of the prior evaluation program might be considered insufficient for some applications, and incremental evaluation might be required. The scope of any such incremental evaluation shall be by agreement between the assigner and the supplier.

In all cases, the evaluation report and the inspection report shall indicate the TWCCEP version (release) to which the evaluation program was conducted.

8.5 Use of data from previous evaluations

Analytical and experimental data acquired in a connection and/or material assessment prior to a TWCCEP evaluation program is referred to as prior evaluation data. Such prior evaluation data may sometimes be used in lieu of some or all analysis or testing required by the TWCCEP evaluation program. Any party involved in TWCCEP program execution may propose use of prior evaluation data, but any such use shall be agreed by the assigner and the supplier.

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In general, the TWCCEP allows use of prior evaluation data when either: 1) that data are fully compliant with TWCCEP requirements or 2) that data are not fully compliant with TWCCEP requirements but some additional conditions are satisfied. The following paragraphs provide provisions for either of the above two scenarios.

The following process shall be followed for use of any prior evaluation data in a TWCCEP evaluation program. Prior evaluation data may be used in a TWCCEP evaluation program if:

a) a person/company who is a substantially qualified party (3.38) to perform connection evaluation (analysis and/or testing, whatever the case might be) and interpret results thereof:

   1) conducts a thorough technical review of the prior evaluation data;

   2) verifies that the scope, procedures, execution history, and documentation that were employed to acquire prior evaluation data have all met or exceeded the respective requirements of the TWCCEP for the candidate connection;

   3) issues a written confirmation that such verification was conducted and includes the conclusions reached;

b) if the person/company in a) acts on behalf of the supplier of the connection for which use of prior evaluation data are proposed, then at least one other person/company that is a substantially qualified party to interpret prior evaluation data and is independent from that connection supplier provides written concurrence with the conclusions of the verification referred to in a).

If a review of prior evaluation data is conducted as referred to in a) and b) and the prior evaluation data is found to not meet all TWCCEP requirements (for example, because significant discrepancies are identified between the prior evaluation and the TWCCEP procedure), then:

c) if the review of prior evaluation data is done by a person/company independent from the supplier of the connection for which use of prior evaluation data are proposed, as discussed in a) above, that person/company shall recommend additional analysis and/or testing to supplement the prior evaluation data such that the combined extent of the prior evaluation data and the additional analysis and/or testing will satisfy all requirements of the TWCCEP; or

d) if the review of the prior evaluation data is done by the supplier of the connection for which use of prior evaluation data are proposed, and that review is verified by an independent party, as discussed in a) and b) above, then the supplier and that independent party shall agree on additional analysis and/or testing to supplement the prior evaluation data such that the combined extent of the prior evaluation data and the additional analysis and/or testing will satisfy all requirements of the TWCCEP.

Upon that additional analysis and/or testing being carried out as discussed in c) or d) and confirmed in writing as having been carried out, the prior evaluation data and the additional analysis and/or testing shall be deemed to jointly satisfy the requirements of the TWCCEP.

Any prior evaluation data used in an evaluation program shall be included in the evaluation report for the corresponding evaluation program.

8.6 Conformance to lower ASLs

Conformance of the assessment results of the candidate connection to the performance requirements for the selected ASL shall be interpreted as conformance to all other ASLs defined by lower temperatures than the ASL to which the candidate connection has been evaluated.

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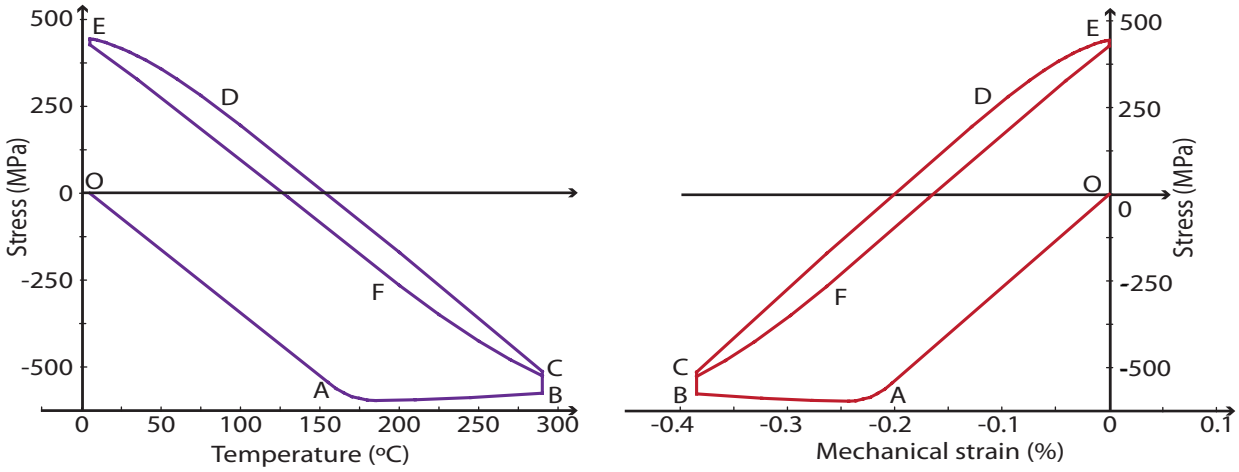
9 Application severity levels

9.1 Thermal well load path

The TWCCEP recognizes that casing connections in thermally-stimulated wells, such as SAGD or CSS wells, experience a common loading scenario in which axial loads on the casing pipe-connection system and internal casing pressures are largely driven by cyclic temperature changes.

Temperature-driven axial force contributes the majority of the loading on the pipe-connection system. As an example, Figure 4 illustrates a typical axial load cycle experienced by L80 casing cycled between a minimum temperature of 5°C and a maximum temperature of 290°C (specifications for temperature ranges distinguished by the TWCCEP are provided in 9.3). The chart on the left side of Figure 4 shows the relationship between the pipe body stress and well temperature, and the chart on the right side shows the same relationship in terms of mechanical strain generated by axially constrained thermal expansion.



a) Stress-temperature plot **b) Stress-strain plot**

Figure 4 — Example of thermal-well load path (1.5 thermal cycles)

The load cycle commences with constrained heating, in which compressive axial stress initially builds according to the elastic stress-strain relationship (load path OA). The casing string yields when the compressive yield strength is reached (at approximately 180°C in this case). The casing response to further temperature increase is influenced by the temperature-dependence of the yield strength, which typically reverses the slope of the stress-temperature curve, although this trend can be somewhat offset by strain hardening (load path AB). During steaming at maximum temperature, stress relaxation occurs, which reduces the compressive axial stress in the pipe-connection system (path BC). When cooling, the string experiences constrained thermal contraction, which generates axial tension (path CD). The reverse loading curve demonstrates a reduction of the elastic range and a corresponding rounded shape of the cyclic stress-strain curve. In the example illustrated in Figure 4, the casing yields again under tension (at approximately 100°C). The maximum tensile stress is reached upon return to the lower-bound temperature (path DE). Heating in the second cycle follows a cyclic stress-temperature (or stress-strain) curve (path EF). Subsequent loading in the second cycle and later cycles qualitatively follows the cyclic heating-cooling loop (path EFCDE), although each cycle might result in a slight change (typically increase) of the tensile stress at the cycle-end. The width of the hysteresis loop EFCDE provides a measure of average pipe-body plastic strain accumulated in each cycle. Specific progression of the load-deformation loops depends on cyclic properties of the casing material. For example, modest increases in the end-of-cycle tension typically occur with further cycling.

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Internal casing pressure typically constitutes a less severe loading component than axial tension and compression, but it might have a significant impact on the casing deformation when the casing yields due to the axial forces. In the event that a connection leaks, the magnitude of the internal pressure can also be expected to impact the leak rate.

Internal pressure loading applied in the TWCCEP's evaluation procedure is based on the assumption that in thermal operations the internal pressure closely follows the saturated-steam relationship with temperature, although it is recognized that cooling can also occur with retained reservoir pressures. The adopted pressure-temperature relationship for saturated steam is illustrated in Figure 5.

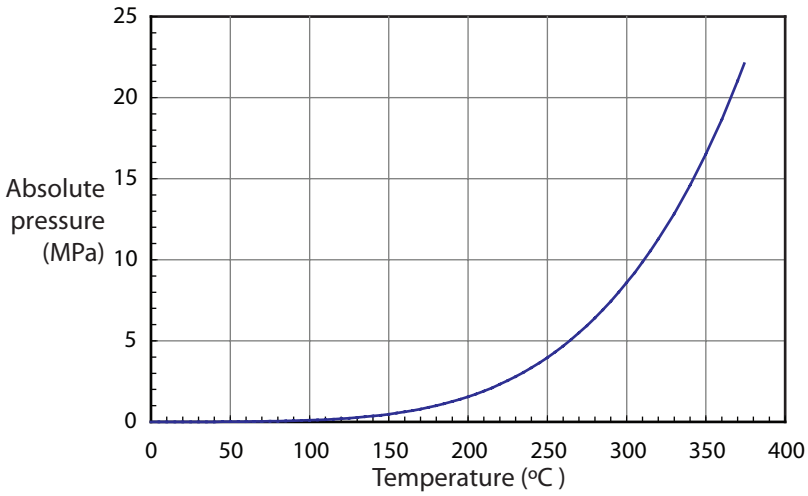

Figure 5 — Relationship between pressure and temperature for saturated steam

The TWCCEP assumes the cyclic loading sequence described in the above paragraphs as the basic load path for the analytical and testing evaluation tasks, with some modifications resulting from practical considerations (also see 6.5.7). The following three characteristic stages of the thermal cycle were chosen as reference loading conditions:

a) connection make-up;

b) maximum-temperature hold;

c) return to low temperature at the end of the thermal cycle.

9.2 Temperature as controlling parameter

The following list summarizes the reasons for which temperature is recognized as the major parameter influencing thermal-well loading and connection sealability and structural response:

— Constrained thermal expansion of cemented casing, when heated to the maximum operating temperature, generates high compressive loads that might lead to pipe body and/or connection yielding. The magnitude of the cyclic axial loads generated during temperature excursions, and the degree of thermally-driven deformation, strongly depend on the applied temperature range;

— In field service, applied internal pressures typically follow the pressure-temperature relationship for saturated steam;

— Properties of casing pipe and connection materials vary with temperature. The material yield strength typically decreases as temperature rises, and creep and relaxation effects become more pronounced at elevated temperatures;

— Elevated temperatures affect properties of connection interfacial components (e.g. thread compounds, coatings), and thus influence their role in premium seal effectiveness. Higher

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temperatures are typically associated with faster property changes in coatings and thread compounds, although resistance to such degradation might vary substantially between different coatings and compounds.

The above list excludes geotechnical activity and corrosive effects, which are not addressed by the TWCCEP.

9.3 Definition of application severity level

Thermal well operations are diverse. While the thermal-well loading sequence is assumed to be common (and consistent with the loading path described in 9.1), utilized temperature ranges vary. Assuming a single reference temperature for connection evaluation purposes would lead to the evaluation conditions being too severe compared to some field applications, and perhaps not severe enough for other applications. To permit consistent use of the evaluation procedure (3.15) for various severities of thermal-well operations, the TWCCEP defines multiple ASLs that relate to increasingly arduous service conditions, and consequently specify increasingly arduous evaluation conditions.

The TWCCEP categorizes the ASLs based on the upper-bound temperature, as shown in Table 3. For example, ASL-290 denotes a severity level choice appropriate for operations in which the maximum operating temperature will not exceed 290°C. Applications in which maximum temperature does not exceed 180°C are not addressed by TWCCEP.

The TWCCEP arbitrarily assumes 5°C as the lower-bound temperature for all ASLs. This temperature is considered conservative for operations in moderate or colder climates, because the casing string is not expected to be at a lower temperature during cementing, and is not expected to cool down to a lower temperature during the operational cycles. While lower-bound temperatures higher than 5°C can be expected in some climates, the TWCCEP assumes the resulting extra conservatism as an additional safety margin that will enable a "qualified" connection to be used in various climates without a need to repeat any testing.

All axisymmetric loads applied in the evaluation procedure are derived from the ASL specifications. Axial loads are strain driven, resulting from constrained thermal expansion and contraction within the range defined by the lower-bound and upper-bound temperatures. Consequently, the magnitudes of axial forces are material-specific. They depend on the coefficient of thermal expansion of the casing pipe (and to a lesser degree of the coupling material), and the material stress-strain characteristics.

Table 3 — TWCCEP application severity levels

Application severity level (ASL)	Maximum operating temperature	Lower-bound temperature	Upper-bound temperature
(C°)			
Not applicable	180		180
240	181-240	5	240
290	241-290	5	290
325	291-325	5	325
350	326-350	5	350

The internal pressures derived from the saturated-steam pressure-temperature relationship are listed in Table 4. Some field applications might involve operational pressures other than the pressures resulting from the saturated steam curve. When the operational pressures are lower than the saturated steam pressure, then the TWCCEP accepts the extra conservatism as a margin that will enable a "qualified" connection to be used in a variety of applications in which internal pressure might vary from time to time. The current TWCCEP version does not address loading scenarios in which the operational pressures exceed the saturated steam pressure. Customized evaluations are recommended for those operations.

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Table 4 — Resultant derivative loads

Upper-bound temperature (C°)	Axial loads (Strain-driven)	Maximum internal pressure (MPa)
180	Resultant from constrained thermal expansion between lower- and upper-bound temperatures	1.0
240		3.3
290		7.4
325		12.1
350		16.5

9.4 Selection of application severity level

The assigner (3.3) shall select the ASL (3.2) for each evaluation program (3.16) at the program onset.

An ASL with an upper-bound temperature higher than the maximum temperature expected in the relevant field service shall be chosen for an evaluation program.

Prior to program commencement, the assigner should consult with the supplier (3.39) to confirm that the selected ASL conforms to the supplier's intended service environment for the candidate connection.

10 Program blocks and tasks

10.1 Evaluation tasks and sequence — Overview

The basic structure of the TWCCEP evaluation procedure is outlined in Figure 6. The procedure consists of the following blocks (groups of related tasks): program specifications; biased test population; specimen procurement; full-scale testing and supplementary analysis; and reporting.

The program specifications block (Clause 11) describes the assigned program roles, the candidate connection, and the selected program options, such as the ASL. If relevant prior data are available and intended for use in the program being commissioned, it needs to be referenced in this block as well. The program specifications are selected in Tasks 1.1 to 1.4.

Selection of program specifications for the candidate connection might impact subsequent use of the program results. For example, since the connection interfacial components (i.e. coating and thread compound) play a fundamental role in connection sealability in thermal applications, the TWCCEP program results are considered valid only for the interfacial components that are included in the candidate connection specifications (and used for the test specimens), unless it is demonstrated that use of a different interfacial component does not result in a substantial change of the candidate connection performance.

Determination of the biased test population (Clause 12) is conducted to derive specifications for the full-scale connection testing specimens. This front-end assessment consists of two tasks: Task 2.1 Initial Material Property Characterization, and Task 2.2 Specimen Configuration Analysis. Task 2.1 is conducted to obtain reference properties of the candidate connection's component material(s). These reference properties are acquired by coupon-scale laboratory tests of a random sample of the connection production material(s), at temperatures spanning the selected ASL. The acquired reference properties are used to formulate a constitutive material model for subsequent numerical simulations. Task 2.2 Specimen Configuration Analysis is a parametric finite-element sensitivity study. It is conducted to select worst-case combinations of geometric and material-property variables allowed by the manufacturing tolerances, and to select target make-up torques for sealability tests. 12.3 describes the scope of this analysis, and Annex A provides associated modelling guidelines.

To facilitate program execution, the material characterization and sensitivity analysis can be performed well in advance of the other evaluation tasks. Pre-existing material data and FEA results can also be used if their conformance to TWCCEP requirements is demonstrated.

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The results of the front-end analysis affect decisions relative to the procurement of specimen material(s) (Clause 13). If material properties are shown to have a significant impact on the candidate connection's structural response, the range of material properties allowed for the test samples is biased to those properties that lead to worst-case combinations of the material variables. If no significant impact of the material variables is found, the test samples can be procured from any material with properties in the range allowed by the connection production specifications.

After the test specimen's mother pipes are procured in Task 3.1, their mechanical properties are verified in Task 3.2, by a limited number of coupon-scale tests. Since the purpose of those tests is to confirm consistency of the test sample material with the specifications defined by the front-end configuration analysis, they can be referred to as quality-assurance checks. The test specimens are then machined and gauged according to the selected geometrical specifications in Task 3.3. Manufacturing variables not predetermined by the TWCCEP are assumed to be within normal production values. It is strongly recommended that duplicate specimens (replacement spares) be manufactured for each full-scale test specimen configuration.

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Block		Task		Description	Clause
1	Program Specifications	1.1	Program Roles	Assignment of program roles	11.2
		1.2	Candidate Connection	Unique identification of pin, box, interfacial component	11.3
		1.3	Program Options	Selection of ASL and optional tasks	11.4
		1.4	Prior Evaluation Data	Use of analysis/test data from prior evaluations	11.5
2	Determination of Biased Test Population	2.1	Initial Material Property Characterization	Material property test of a random production sample Reference properties for input into FEA model	12.2
		2.2	Specimen Configuration Analysis	Parametric analysis to determine critical design-specific configurations for test specimens	12.3
		2.2.1	Nominal Reference	Nominal geometry, material properties, assembly torque	
		2.2.2	Specimen Geometry	Worst diametric interferences and thread tapers	
		2.2.3	Seal Tapers (*)	Variations due to tolerances for seal tapers	
		2.2.4	Material Properties	Worst yield strength range for pin and box materials	
		2.2.5	Make-up Torques	Target make-up torques for sealability tests	
		2.2.6	Test vs Production (*)	Best test specimen vs worst production specimen	
3	Test Specimen Procurement	3.1	Specimen Pipe Procurement	Pipe joints and coupling stock as per specifications for biased test population	13.2
		3.2	Material Property Verification	Verification of material properties of procured pipes	13.3
		3.3	Specimen Machining and Gauging	Per specifications for biased test population 1 2 3 4 5 6 Spares	13.4, 13.6
4	Full-Scale Tests and Supplementary Analyses	4.1	Galling Resistance Test	Multiple make-ups and break-outs 1 2 3 5	14.3
		4.2	Thermal Cycle Test	Axisymmetric configuration and loading 10 thermal cycles from room to maximum ASL temperature 3 4 5 6 Specimens re-labeled based on results of thermal cycle test: RX RY	14.4
		4.3	Bending Evaluation	Sensitivity to non-axisymmetric bending Bending limit for structural integrity and sealability	14.5
		4.3.1	Bending Analysis (*)		
		4.3.2	Bend Test (*)	2 RY	
		4.4	Limit-Strain Test	Strength and sealability at increasing tensile strains	14.6
		4.4.1	Loc. Strain Seepage (*)	1 RX	
		4.4.2	Tension Limit	1 RX	
		4.5	As-Tested Configuration Analysis (*)	Analysis of as-tested configuration in support of acquired experimental results	14.7
5	Reporting	5.1	Evaluation Report	Data and results from analysis and testing Comparison with threshold performance requirements	15
		5.2	Inspection Report	Compliance with TWCCEP requirements	

(*) - denotes optional task

Figure 6 — Blocks and tasks of TWCCEP evaluation procedure

Six specimens are subjected to full-scale testing. Clause 13 describes specimen configurations and the corresponding numbering convention. As much as practical, the configuration of each specimen is

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designed to represent the worst-case combination of tolerances with respect to performance measures assessed in those tests to which the specimen is subjected. The testing sequence for each specimen is illustrated in Figure 6 (specimen numbers are marked in blue boxes).

TWCCEP's fourth block contains specifications for full-scale tests and supplementary analyses (Clause 14). Some tasks in this block are mandatory and some are optional. The mandatory tasks in this block are: Task 4.1 Galling Resistance Test, Task 4.2 Thermal Cycle Test, and Task 4.4.2 Tension Limit. The optional tasks are: Task 4.3 Bending Evaluation (both subtasks), Task 4.4.1 Localized Strain Seepage, and Task 4.5 As-Tested Configuration Analysis.

Table 5 summarizes the mandatory and optional tasks and associated data categories. The task outcomes are categorized according to the data types described in 6.3.7: input for subsequent tasks, key performance measures, and auxiliary performance data.

Table 5 — Mandatory and optional tasks and resultant data categories

Task		Completion	Resultant data category	Clause
2.1	Initial Material Property Characterization	Mandatory	Input for subsequent tasks	12.2
2.2	Specimen Configuration Analysis:		Input for subsequent tasks and auxiliary performance data	12.3
	2.2.1 Nominal Reference	Mandatory		
	2.2.2 Specimen Geometry	Mandatory		
	2.2.3 Seal Tapers	Optional		
	2.2.4 Material Properties:			
	2.2.4.1 Pin Yield Strength	Mandatory		
	2.2.4.2 Box Yield Strength	Optional		
	2.2.5 Make-Up Torques	Mandatory		
	2.2.6 Test Versus Production	Optional		
3.2	Material Property Verification	Mandatory	Input for subsequent tasks	13.3
4.1	Galling Resistance Test	Mandatory	Key performance measure	14.3
4.2	Thermal Cycle Test	Mandatory	Key performance measure	14.4
4.3	Bending Evaluation:		Auxiliary performance data	14.5
	4.3.1 Bending Analysis	Optional		
	4.3.2 Bend Test	Optional		
4.4	Limit-Strain Test:			14.6
	4.4.1 Localized Strain Seepage	Optional	Auxiliary performance data	
	4.4.2 Tension Limit	Mandatory	Key performance measure and auxiliary performance data (*)	
4.5	As-Tested Configuration Analysis	Optional	Auxiliary performance data	14.7
(*) - data is auxiliary beyond average thermal strain. See 14.6.				

The scope of the full-scale tests has been structured to reflect the loading encountered by casing and connection systems during assembly and field service. The galling resistance test is conducted to verify that the candidate connection can withstand multiple make-ups and break-outs without severe galling of thread surfaces or appreciable deterioration of seal surfaces. The thermal cycle test assesses the candidate connection sealability and structural integrity under combined, thermally-induced cyclic loading. This test includes specimen bake-out and multiple thermal cycles with temperature and pressure changes consistent with the selected ASL. Four specimens are cycled, either in one or more strings or individually. Upon completion of the thermal cycle test, the specimens are re-ordered according to

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their performance in that test. One cycled specimen and one non-cycled specimen are designated for the optional bend test, in which the connection sealability and structural integrity are assessed under curvature loading. One cycled specimen and one non-cycled specimen are subjected to the limit-strain test, in which limits of connection structural integrity and (optionally) sealability are assessed under increasing, tensile axial strain. Detailed test procedures and threshold performance requirements for each test are included in Clause 14.

Galling resistance, structural strength, and sealability measured in the full-scale tests are the only TWCCEP evaluation results that are compared to threshold performance requirements; only these full-scale test results contribute to the pass-fail assessment of the tested candidate connection.

Supplementary analyses are recommended to evaluate connection performance indicators that might be critical for some operations but not for others. Task 4.3.1 Bending Analysis is recommended for applications in which severe bending and/or shear is anticipated during installation or during well operation due to geo-mechanical loading. Task 4.5 As-Tested Configuration Analysis is recommended to be conducted in support of interpreting the acquired experimental results; for example when some tested connections are considered for classification as excluded connections (3.21).

Results of supplementary analysis are not compared to threshold performance requirements, but may be used to specify additional testing to assess connection performance under application-specific conditions that are not simulated in the mandatory tests.

Program reporting is conducted in Task 5.1 Evaluation Report. The evaluation report contains all analytical and test data collected in the evaluation program. Data acquired in full-scale tests is compared with TWCCEP's threshold performance requirements (3.45). The inspection report is prepared in Task 5.2 and attached to the evaluation report. The inspection report verifies compliance of the conducted evaluation program with TWCCEP's procedures. Clause 15 describes the reporting requirements in detail.

10.2 Critical path tasks

TWCCEP distinguishes several tasks in the evaluation procedure (3.15) as critical path tasks, whose output has substantial impact on subsequent task execution and on resultant assessment of the candidate connection (3.7). A list of the critical path tasks is given in Table 6.

TWCCEP recommends that execution and results of the critical path tasks be independently reviewed, to ensure that correct output from those tasks is incorporated in other related tasks and in comparisons with the threshold performance measures (3.45). The extent of such an independent review should be considered in view of guidelines provided in Annex C, and selected by agreement between the assigner (3.3)and the supplier (3.39).

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Table 6 — Critical path tasks

Task		Clause
1.4	Prior Evaluation Data	11.5
2.1	Initial Material Property Characterization	12.2
2.2	Specimen Configuration Analysis:	12.3
	2.2.1 Nominal Reference	
	2.2.2 Specimen Geometry	
	2.2.3 Seal Tapers (*)	
	2.2.4 Material Properties (*)	
	2.2.5 Make-Up Torques	
	2.2.6 Test versus Production	
3.2	Material Property Verification	13.3
3.3	Test Specimen Machining and Gauging	13.4, 13.6
4.1	Galling Resistance Test	14.3
4.2	Thermal Cycle Test	14.4
4.3	Bending Evaluation:	14.5
	4.3.1 Bending Analysis (*)	
	4.3.2 Bend Test (*)	
4.4	Limit-Strain Test:	14.6
	4.4.1 Localized Strain Seepage (*)	
	4.4.2 Tension Limit	
4.5	As-tested Configuration Analysis (*)	14.7
(*) – applies only to the performed optional tasks		

11 TWCCEP program specifications

11.1 General requirements

This Clause describes the TWCCEP tasks included in the program specification block (see Figure 6). The tasks in this block are conducted to specify information that will allow unique identification of parties involved in the evaluation program (3.16), the candidate connection (3.7), and the options selected for the evaluation procedure (3.15).

This block contains four tasks: Task 1.1 Program Roles (11.2), Task 1.2 Candidate Connection (11.3), Task 1.3 Program Options (11.4), and Task 1.4 Prior Evaluation Data (11.5). Details of those four tasks are described in the following sub-clauses of Clause 11. All tasks in this block are mandatory.

Additional information shall be included in program specifications when necessary to achieve unique identification of the candidate connection and the selected program options.

All information obtained in the program input shall be documented in the evaluation report (3.17).

11.2 Identification of program roles

Task 1.1 is performed to identify all parties known to be involved in the evaluation program at its onset, and their assigned tasks. If other parties become involved in the evaluation program during its execution, then the information about those parties shall be added to program specifications accordingly.

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If multiple parties are assigned to a role, the program specifications shall indicate the assigned sets of responsibilities within the shared role.

Table 7 illustrates the required extent and recommended format of program specifications on role assignments. Specific assignments in Table 7 are listed as examples only, and are not to be interpreted as TWCCEP provisions or recommendations.

Table 7 — Example of program specifications for role assignments

Program role	Company	Responsibility/task	Source/sub-task
Assigner	Operator A	Selection of ASL	This example assumes a program jointly commissioned/ funded by Operator A and Manufacturer B
	Manufacturer B	Selection of candidate connection	
		All other assigner tasks are shared	
Supplier	Manufacturer B	Provision of mother pipe and test samples	
Evaluator	Manufacturer B	Material property characterization	Prior evaluation data
		Specimen configuration analysis	Existing previous results
	Engineering Firm C	Specimen configuration analysis	Additional analysis
	Engineering Firm D	Full-scale testing	
Inspector	Engineering Firm D	Specimen machining and gauging	Third-party thread/seal gauging
	Engineering Firm C	Full-scale testing	Galling resistance test
	Engineering Firm E	Full-scale testing	Thermal cycle test
	Engineering Firm F	All other inspection tasks	

11.3 Identification of candidate connection

In Task 1.2, specifications for the candidate connection (3.7) shall uniquely identify the connection product that is the subject of assessment in the evaluation program (3.16), and the candidate connection's assembly procedure recommended by the supplier (3.39). Table 8 illustrates the required scope of, and recommended format for, the candidate connection specifications.

The first group of specifications in Table 8 relates to the candidate connection's production specifications, and include the connection name, size, weight, pin and box materials, and interfacial components (3.24).

If the candidate connection's pin and/or box materials are manufactured to a design-specific set of specifications that are different from API grade specifications (e.g. a narrowed-down range of yield strength), then those design-specific production manufacturing specifications shall be identified in Task 1.2 and subsequently used in determination of the biased test population (Task 2.1 and 2.2, see 12.2 and 12.3.1) and for procurement of specimens for full-scale testing (Task 3.1, see 13.2).

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Table 8 — Extent and format of candidate connection specifications

1. Identification of candidate connection	
Product name	
Size	
Weight	
Pin material designation (Note 1)	
Box material designation (Note 1)	
Interfacial components	
2. Connection schematic (Note 2)	
Diagram: attach separate page(s) with schematic cross-sectional diagram	
3. Production specifications (Note 3)	
Process control/quality management plan	Drawing or document revision and date
Pin drawing(s)	
Box drawing(s)	
Pin surface treatment/type specification	
Box surface treatment/type specification	
Swage/stress relief procedure	
Gauge calibration procedure	
Gauging and geometry inspection/QA procedure	
Material property inspection/QA procedure	
Interfacial component inspection/QA procedure	
4. Assembly specification	
Mill make-up procedure	Document revision and date
Field running procedure	
Connection repair procedure	
Sample make-up curves (Note 4)	Reference to make-up procedure
Note 1 - include applicable sub range of API grade specifications, if applicable.	
Note 2 - provide detail to the extent needed to perform evaluation tasks.	
Note 3 - production specifications must allow complete identification of the manufacturing process.	
Note 4 - curves must show torque-turn up to maximum achieved torque.	

The second group of specifications relates to the candidate connection's schematic drawings. The schematic drawings shall contain sufficient amount of detail to enable execution of the TWCCEP evaluation tasks.

The third group of input specifications relates to the candidate connection's manufacturing procedure. These specifications are required to uniquely identify the manufacturing process of the evaluated product, for later reference. The TWCCEP does not require provision of confidential design or manufacturing information.

The fourth group of candidate connection input specifications relates to connection assembly. The mill make-up and field running procedures and the connection repair procedure are provided for use in Task 4.1 Galling Resistance Test (14.3). Samples of make-up torque-turn curves are provided to verify accuracy of the candidate connection model in Task 2.2 Specimen Configuration Analysis (12.3.1).

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11.4 Program options

In Task 1.3, the assigner (3.3) shall consider and select from the following program-execution options:

a) Application severity level (3.2);

b) Task 2.2.3 Seal Tapers – indicate if that analysis will be carried out in the evaluation program or not;

c) Task 2.2.4.2 Box Yield Strength – indicate if that analysis will be carried out in the evaluation program or not, and if yield strength of the box material will be considered in determination of the biased test population;

d) Task 2.2.6 Test versus Production – indicate if that analysis will be carried out in the evaluation program or not;

e) Task 4.3 Bending Evaluation – indicate the selected scope of the bending evaluation: none, bending analysis only, bend test only, or both options;

f) Task 4.4.1 Localized Strain Seepage – indicate if that test will be carried out in the evaluation program or not;

g) Task 4.5 As-Tested Configuration Analysis – indicate if that analysis will be carried out in the evaluation program or not.

The assigner shall communicate the selected options to the supplier (3.39), the evaluator (3.18)and the inspector (3.23). The evaluator shall document all selected options in the evaluation report.

11.5 Data from prior evaluations

In Task 1.4, input of any prior evaluation data intended for use in the evaluation program shall be conducted as follows:

a) source and contents of any existing data that is intended to be utilized in the current evaluation program as prior evaluation data shall be identified;

b) conformance of that existing data to TWCCEP requirements for prior evaluation data shall be verified as stipulated in 8.5.

12 Determination of biased test population

12.1 Overall description

This Clause describes the second TWCCEP evaluation program block: determination of biased test population (see Figure 6). The main purpose of this block is to select those combinations of design variables and make-up torques that represent worst-case scenarios with respect to the assumed performance measures for the candidate connection. The selected combinations are subsequently used to derive specifications for the connection specimens to be manufactured for full-scale testing and for the target make-up torques to be applied upon specimen assembly for sealability tests. The secondary purpose of this block is to provide reference results for determination of load steps that will be applied in physical testing.

This program block consists of two tasks: Task 2.1 Initial Material Property Characterization (12.2), and Task 2.2 Specimen Configuration Analysis (12.3). Details of those two tasks are described in the following clauses. Implications of the front-end analysis results on decisions relative to procurement of the test specimens are also described.

To facilitate program execution, the material characterization task and the specimen configuration analysis can be performed in advance of the other evaluation tasks.

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Material property specifications (for example, yield strength range) used for Task 2.1 and Task 2.2 shall be consistent with candidate connection specifications provided in Task 1.2 (11.3).

Prior evaluation data on material property characterization, specimen configuration and make-up torque analysis may be utilized in lieu of some or all subtasks of Task 2.1 and Task 2.2, if applicability of that prior evaluation data to the candidate connection and its conformance to TWCCEP requirements is demonstrated according to the provisions in 8.5. In such cases, prior evaluation data can be used, for example, to select specimen specifications and/or make-up torques for full-scale testing without conducting all material characterization and analysis cases required in Tasks 2.1 and 2.2.

Results of analyses conducted to determine specifications for the biased test population are not comparable with TWCCEP threshold performance requirements.

12.2 Initial material property characterization

12.2.1 Task description

Task 2.1 Initial Material Property Characterization is conducted to obtain reference material properties of the candidate connection pipe materials, including tubulars for pin components and coupling stock for box materials. The reference properties include tensile stress-strain response and thermal expansion coefficient. These properties are assessed by coupon-scale laboratory testing of samples representative of the connection-production materials, at temperatures spanning the selected ASL. In this document, such reference properties are called as-characterized material properties. The acquired as-characterized material properties are used to define constitutive material models for subsequent use in Task 2.2 Specimen Configuration Analysis (see 12.3.2).

Mechanical properties of pipe materials used for full-scale evaluation tests will in general not correspond to those of all of the pipes and couplings used in the field. Variability exists in material properties at both ambient and elevated temperatures. Analyses of connection models have shown that yield and post-yield material properties affect contact forces in premium connection seals, and thus variability in those properties can be expected to influence connection sealability in qualification tests and field use.

The TWCCEP provides the following procedure to account for variability in material properties of the pin and box components of the candidate connection. First, representative samples of the pin and box pipe materials are tested to obtain the as-characterized material properties (see 12.2.2, 12.2.3 and 12.2.4). Those as-characterized properties are used in Task 2.2 Specimen Configuration Analysis (12.3). Upon procurement of materials for the full-scale test specimens, conformance of their properties with requirements for the biased test population is verified by physical testing (13.2 and 13.3).

12.2.2 Testing conditions and scope

12.2.2.1 Stress-strain response

The stress-strain response of typical OCTG materials is known to depend on temperature and rate at which the material is strained. Evaluation of the temperature-dependence of the stress-strain material response is mandatory, unless existing material testing results are utilized as prior evaluation data. Since the purpose of this initial evaluation is to support subsequent specimen configuration analysis, and given the complexity and difficulty associated with evaluating rate-dependence, that aspect of the material evaluation is recommended but not required.

The following testing scope shall be conducted for representative samples of the pin and box components. At least one uniaxial tensile test shall be conducted at each of the following temperatures, up to the temperature corresponding to the selected ASL:

— 15°C to 35°C (ambient temperature)

— 180°C (transition temperature)

— 240°C (ASL-240)

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— 290°C (ASL-290)

— 325°C (ASL-325)

— 350°C (ASL-350)

Circumferential variability in properties should be checked by conducting at least one additional test on a sample taken approximately 120° away (circumferentially) from the first sample. It is recommended that the circumferential variability test(s) be performed at 180°C. If a variation of more than 10 % is observed in the measured stress at the appropriate yield strain specified in ISO 11960 (typically 0.5 % or 0.6 %), similar tests should be conducted at each of the other test temperatures. For each temperature at which multiple tests are conducted, the resulting stress-strain curve that exhibits the lowest yield strength should be used as the as-characterized material description. If variability in test results is suspected to be an artefact of the testing system, further testing should be performed to determine the repeatability of the results.

Table 9 summarizes the scope for Task 2.1 Initial Material Property Characterization, including the mandatory and recommended tensile tests for each ASL.

Table 9 — Scope of material characterization tensile tests

Application Severity Level	Mandatory tensile tests	Recommended circumferential consistency test(s)	Total number of tests = mandatory plus recommended
240°C	3 (ambient, 180°C, 240°C)	At least 1 test (recommended at 180°C)	4
290°C	4 (ambient, 180°C, 240°C 290°C)		5
325°C	5 (ambient, 180°C, 240°C 290°C, 325°C)		6
350°C	6 (ambient, 180°C, 240°C 290°C, 325°C, 350°C)		7

12.2.2.2 Thermal expansion coefficient

In Task 2.1 Initial Material Property Characterization, the TWCCEP allows the average coefficient of thermal expansion (CTE_a) of each material to be determined according to one of the following methods, prior to commencing Task 2.2 Specimen Configuration Analysis:

a) assume an average CTE_a of 14 με/°C, if it is considered representative of the pipe material over the temperature range corresponding to the selected ASL;

b) quantify the thermal expansion coefficient over the temperature range corresponding to the selected ASL by laboratory tests as described for Task 3.2 Material Property Verification (13.3), and calculate an average value corresponding to that temperature range;

c) use existing data and/or test results from a material sample if they are considered representative for the temperature range corresponding to the selected ASL;

d) calculate CTE_a according to a temperature-dependent formula that is considered representative over the temperature range corresponding to the selected ASL.

The method for determination of CTE_a in Task 2.1 shall be selected by agreement between the assigner, the supplier and the evaluator. The same method shall be adopted for testing the pin material and the box material. The adopted method and the assumed and/or measured CTE_a value(s) shall be documented in the evaluation report.

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As an example, in independent prior investigations the following temperature-dependent formula was derived for several carbon steel casing materials to determine an average thermal expansion coefficient between 5°C and an elevated temperature *T*, in which temperature *T* has Celsius units:

$$CTE_a = (10.94 + 0.00813 * T) * 10^{-6} /°C$$

Measurement of actual CTE_a of pipes used for manufacturing specimens for physical tests is addressed in 13.3.4.

12.2.2.3 Material strip specimens

The material strip specimens (3.31) for stress-strain characterization shall be longitudinal strip specimens cut from full-circumference "coupon" sections of the source pipe. Where practical, the material strip specimens should utilize a full-thickness rectangular cross-section or equivalent cylindrical or semi-cylindrical cross-section, and specimen geometry should be selected to satisfy the control and measurement requirements defined in 12.2.3. In the as-characterized evaluation, specimen properties will be interpreted as an indication of average mechanical response.

Relative circumferential locations of all material strip specimens shall be recorded as they are removed from the mother tubes. Where possible, all material strip specimens should be removed from the same cross-section. If this is not possible, extra strip specimens shall be extracted from an adjacent cross-section not more than 0.3 m (12 in) away, and from the same circumferential position. Material strip specimens manufactured from ERW tube should be extracted at least 90° from the weld centreline. For small-diameter tubes for which the above-recommended specimen spacing is not possible, the circumferential distance between the specimen locations and the weld centreline should be maximized.

12.2.3 Procedure for tensile tests

Tensile tests shall be conducted using testing procedures that meet ASTM specifications listed in Clause 3 for ambient and elevated-temperature material mechanical property tests. It is recommended that specimen loading in the tests be conducted in a strain-control mode.

Strain in reduced section of each material strip specimen shall be measured with an extensometer to a strain of at least 2 %. It is recommended that the strain be measured by an extensometer up to a strain beyond the highest global strain attained in the candidate connection. If the extensometer data are not available to this strain level, stroke data gathered during the material test must be rigorously interpreted to provide a suitable estimate of the stress-strain response.

Example of strain-strain data to be acquired in the tensile tests are shown in Figure 7. These results need to be further processed and interpreted in order to obtain material property input for modelling purposes. The result interpretation procedure is described in 12.2.4.

12.2.4 Interpretation and processing of tensile test results

12.2.4.1 Scope of result interpretation

Once testing results are obtained, they must be interpreted for subsequent use in Task 2.2. The following constitutive material descriptions are the product of this interpretation:

— as-characterized;

— minimum-yield;

— maximum-yield.

The as-characterized set is consistent with results of the conducted physical testing, for example those shown in Figure 7. The minimum-yield set is meant to approximate results that would be obtained if tests were conducted on samples with the minimum ambient-temperature yield strength. Similarly, the maximum-yield properties represent an estimate of the properties that would be measured from

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samples with the maximum ambient-temperature strength in the material's yield strength range. This range is typically defined by the API grade designation, but if a manufacturer certifies that the ambient-temperature yield strength range of its production material is smaller than the API range, then the maximum and minimum of the manufacturer's claimed yield range may be used instead of the maximum and minimum of the API range. If the connection configuration meets TWCCEP performance requirements through use of a non-standard yield strength range, close attention should subsequently be paid to the strength of field-installed tubulars to ensure the material strength remains within the range considered in the TWCCEP evaluation.

Ideally, the minimum-yield and maximum-yield constitutive descriptions should indicate the stress response of the material as a continuous function of strain and temperature. Such models are complex, particularly where cyclic behaviour occurs. As a minimum, the derived constitutive descriptions shall contain adequate detail to provide the monotonic stress-strain response of the material at each tensile-test temperature.

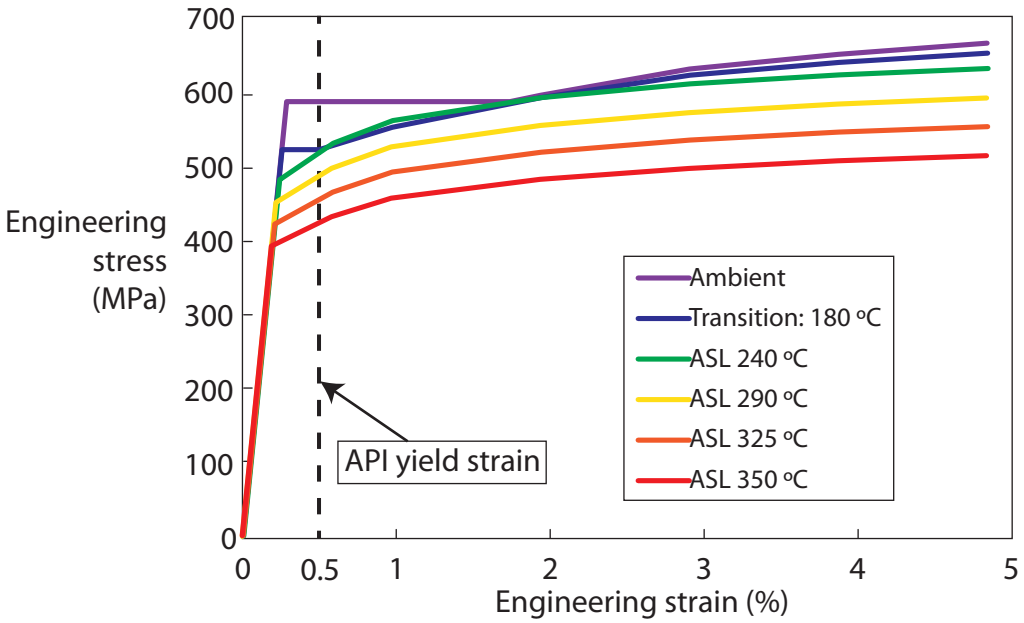

Figure 7 — Examples of as-characterized monotonic stress-strain curves

12.2.4.2 As-characterized constitutive model

Yield strengths derived from the material tests shall be tabulated and used to create a thermal degradation function that non-dimensionally describes strength variations with temperature. Yield strengths shall be determined from the measured stress at the yield strain specified by API for the material grade being tested.

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