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Design of Subsea Well Intervention Systems Using Non-ferrous Alloys

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API RECOMMENDED PRACTICE 17G3
FIRST SECOND, SEPTEMBER 2025



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1 **Titanium Alloy Grades..... 4**
2 **Aluminum Alloys 12**

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Introduction

This document is not intended to be a standalone document from API 17G, rather a complement to current engineering practices set forth by API 17G with the inclusion of titanium and aluminum alloys.

It is important to note that certain design guidelines will supersede some API 17G requirements due to the material properties of titanium and aluminum. These guidelines will be noted and emphasized for clarity and to resolve conflicting design and test procedures between the API 17G3 and the parent document.

It is necessary that users of this recommended practice be aware that additional or different requirements that can better suit the demands of a particular service environment, the regulations of a jurisdictional authority, or other scenarios not specifically addressed in this recommended practice may be applied as required. This document is a recommended practice and it is not intended to replace sound engineering judgment.

One of the drivers for using titanium for the riser is the natural flexibility of titanium over traditional materials such as steel.

As demonstrated in Figure 1, from this side-by-side analysis of using steel vs titanium to construct a tapered stress joint above the well control package, you find the titanium stress joint provides a 50 % improvement in both wave height capacity (Hs) and vessel watch circle radius (vessel offset).

This analysis was based on an alloyed titanium stress joint example in simulated North Sea currents and wave conditions, along with a water depth of 80 m. All loads to the stress joint remain within the normal design limits.

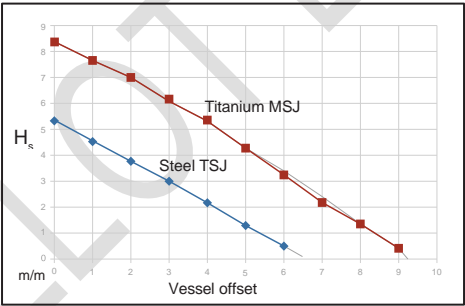


Figure 1—Steel and Titanium Stress Joints

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Design of Subsea Well Intervention Systems Using Non-ferrous Alloys

1 Scope

This recommended practice provides design guidelines for the use of non-ferrous materials in subsea intervention systems and components.

2 Normative References

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

API Specification 17D, *Design and Operation of Subsea Production Systems—Subsea Wellhead and Tree Equipment*

API Standard 17G, *Design and Manufacture of Subsea Well Intervention Equipment*

API Technical Report 17TR8, *High-Pressure High-Temperature Design Guidelines*

API Specification 20F, *Corrosion-resistant Bolting for Use in the Petroleum and Natural Gas Industries*

API 579-1, *Fitness-for-Service*

ANSI ¹/NACE MR0175 ²/ISO 15156 ³ (all parts), *Petroleum and natural gas industries—Materials for use in H₂S-containing environments in oil and gas production*

ASME Boiler and Pressure Vessel Code (BPVC) ⁴, Section VIII: Pressure Vessels; Division 2: Alternative Rules, 2019 Edition

ASME Boiler and Pressure Vessel Code (BPVC), Section VIII: Pressure Vessels; Division 3: Alternative Rules for Construction of High Pressure Vessels, 2019 Edition

ASME FFS-1, *Fitness-for-Service*

ASTM ⁵ E399, *Standard Test Method for Linear-Elastic Plane-Strain Fracture Toughness of Metallic Materials*

ASTM E647, *Standard Test Method for Measurement of Fatigue Crack Growth Rates*

ASTM E992, *Practice of Determination for Fracture Toughness of Steels Using Equivalent Energy Methodology*

ASTM E1290, *Standard Test Method for Crack-Tip Opening Displacement (CTOD) Fracture Toughness Measurement*

ASTM E1820, *Standard Test Method for Measurement of Fracture Toughness*

¹ American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, www.ansi.org.

² NACE International, 15835 Park Ten Place, Houston, TX 77084, www.nace.org.

³ International Organization for Standardization, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, www.iso.org.

⁴ ASME International, 2 Park Avenue, New York, NY 10016-5990, www.asme.org.

⁵ ASTM International, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania 19428, www.astm.org.

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BS⁶ 7910, *Guide to methods for assessing the acceptability of flaws in metallic structures*

DNV-RP-B401⁷/NACE SP0176, *Cathodic protection design*

DNV RP-F201, *Design of Titanium Risers*

3 Terms, Definitions, Acronyms, and Abbreviations

3.1 Terms and Definitions

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

3.1.1

accidental loading

A worst-case scenario loading state determined by the operator.

3.1.2

alpha case

A brittle phase found on the surface of titanium created when titanium is heated in air to approximately 1100 °F or higher. This layer should be removed by machining or chemical milling prior to placing the part into service—reduces fatigue strength and the ductility values of reduction of area and elongation percent.

3.1.3

design validation

Process of proving a design by testing to demonstrate conformity of the product to design requirements.

3.1.4

fracture toughness

Property of a material that measures the resistance to failure resulting from crack propagation.

3.1.5

hydride

The anion of hydrogen, H⁻. Can cause embrittlement in titanium alloys.

3.1.6

tensile strength (ultimate)

TS

The maximum load before failing or breaking divided by the original cross-sectional area.

3.1.7

yield strength

YS

Stress level, measured at both room temperature and elevated temperature, at which material plastically deforms and does not return to its original dimensions upon release.

3.2 Acronyms and Abbreviations

CTOD	crack tip opening displacement
FEA	finite element analysis
HIC	hydrogen-induced cracking

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⁶ BSI, 12950 Worldgate Drive, Suite 800, Herndon, VA 20170, www.bsigroup.com.

⁷ DNV GL, Veritasveien 1, 1363 Hovik, Norway, www.dnvgl.com.

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MSJ	modular stress joint
NDT	nondestructive testing
SCC	stress corrosion cracking
Sm	design stress intensity
SMYS	specified minimum yield strength
SSC	sulfide stress cracking
Sy	material specified minimum yield strength
TS	tensile strength
TSJ	tapered stress joint
UNS	Unified Numbering System
YS	yield strength

4 Titanium Group

4.1 Objective

4.1.1 General

This section provides guidelines and requirements for use of titanium alloys for subsea intervention systems. Titanium grades provide high strength to weight ratio, low modulus of elasticity, and low marine and general corrosion rates. This section is a gap analysis to the main document and an informative tool in selecting the proper grade of titanium per project requirements.

4.1.2 Application

Titanium grades are successfully used in intervention service when proper design, manufacturing, and heat treatments are used.

The essential requirements in the alloy selection, manufacturing, quality controls, and certification are outlined in 4.2.

Titanium alloys shall be annealed, solution treated and aged, or beta anneal conditioned to meet the mechanical properties for the application. These grades, denoted in Table 1, are corrosion resistant, fulfilling ANSI/NACE MR0175/ISO 15156 requirements where applicable.

Some of the titanium alloys suitable for subsea well intervention system are given in Table 1.

Typically, use of titanium alloys is for tension stress joint, slick joint, riser joints, metal seals, keel joints, fasteners, and tension ring.

Titanium grades for use in H₂S service shall include qualification with sulfide stress cracking (SSC) testing. Specific application or other testing as appropriate may be used if agreed with the end user.

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Table 1—Titanium Alloy Grades

Common Alloy Designation	UNS Number ^a	NACE MR0175 Service	Yield Strength ^b ksi	Tensile Strength ^b ksi
Grade 1—CP1	R50250	Yes	20	35
Grade 2—CP2	R50400	Yes	40	50
Grade 5—Ti-6Al-4V	R56400	No	120	130
Grade 9—Ti-3Al-2.5V	R56320	No	70	90
Grade 12—Ti-0.3Mo-0.8Ni	R53400	Yes	50	70
Grade 19 ^c —Ti-3Al-8V-6Cr-4Zr-4Mo	R58640	Yes	110–170	115–180
Grade 23—Ti-6Al-4V ELI	R56407	No	110	120
Grade 25—Ti-6Al-4V-0.5Ni-0.06Pd	R56403	Yes	120	130
Grade 28—Ti-3Al-2.5V-0.1Ru ELI	R56323	Yes	70	90
Grade 29—Ti-6Al-4V-0.1Ru ELI	R56404	Yes	110	120
Titanium 6246 ^c —Ti-6Al-2Sn-4Zr-6Mo	R56260	Yes	135–165	145–175
^a Unified Numbering System (UNS). ^b Minimum values. ^c Heat treat dependent.				

4.2 Design

4.2.1 General

Physical properties like modulus of elasticity, thermal expansion coefficient, thermal conductivity, and thermal diffusivity should be considered at maximum design temperature.

The maximum hardness of different grades shall comply with ANSI/NACE MR0175/ISO 15156-3.

4.2.2 Design Considerations

Due to the differences in material properties between steel and titanium (see 4.10.4), the impact of each of the following on the use of titanium in subsea application shall be determined:

- results of finite element analysis (FEA),
- effects of yield strength/tensile strength (YS/TS) ratio,
- modulus of elasticity,
- surface stresses (residual/applied),
- localized plasticity (yielding),
- material substitutions,

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— fatigue analysis.

Failure to address these issues and direct substitution with another material may result in catastrophic failure.

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4.2.3 Prevention of Creep

Creep propagation is a design input when working with titanium alloys, including working at ambient temperatures at high loads. Allowable operating temperature ranges shall be defined and documented. Changes to specified minimum yield strength (SMYS) due to temperature effects shall be included in equipment design documentation as a part of any stress calculations.

Option 1—Working stresses shall remain below 58 % SMYS at design temperature per ASME *BPVC, Section VIII, Division 2* to prevent creep propagation.

Option 2—Manufacturer can test the material(s) specifically for the intended application and apply the following rules to define allowable stress and prevent creep. The normal design stress shall not exceed the lowest of the following:

- 67 % of SMYS;
- 100 % of the average stress required to produce a creep rate of 0.01 %/1000 hr⁸, when tested at or above design temperature.

4.2.4 FEA Design Verification

Design verification shall be performed to ensure that the titanium equipment design conforms to applicable functional specifications and serviceability criteria. Design validation shall be performed to ensure that titanium equipment protects against failure modes identified for the specific equipment. The impact of the following items shall be evaluated as part of design verification and validation:

- 1) global plastic collapse,
- 2) local failure due to excessive strain (local strain limit damage),
- 3) ratcheting effects,
- 4) plastic collapse under the hydrostatic test condition,
- 5) fatigue assessment (life-cycle estimation).

The loads obtained from the functional specifications shall form the design basis for the titanium equipment and shall include specified operating pressure, temperature, and external loads as well as the corresponding cyclic loading (loading histogram) for significant events that are applied to the equipment.

NOTE Regulations from a jurisdictional authority may impose additional or different requirements for a particular service environment.

Where API product standards exist with specific design factors for titanium equipment, these factors should be satisfied as a minimum.

4.2.5 Validation

The design validation process is required to demonstrate that the equipment maintains the mechanical integrity and functionality/operability relative to its functional specifications.

Design validation should have the following components.

- Validation of materials used for the design: Material properties, service and application limits used in the

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analyses should be based on test data or recognized sources/literature.

⁸ ASME BPVC, Section II, Part D, Appendix 1.

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- Degradation mechanisms that should be considered in the material validation process may include, but not be limited to:
 - temperature;
 - corrosion;
 - fatigue;
 - stress corrosion cracking (SCC);
 - hydrogen-induced cracking (HIC);
 - erosion/corrosion; and
 - other corrosion mechanisms, etc.

4.2.6 Design Life

Design life and service life shall be specified; see API 17G, Annex F. If the service life has not been specified, a minimum of five years shall be assumed.

4.2.7 FEA Design

FEA analysis should be done on titanium subsea equipment. Accidental loading should be applied for worst-case scenario. Localized plastic yielding up to 2 % shall be deemed acceptable.

Critical defect size shall be accounted for during FEA analysis. Critical defect size shall be determined for specific equipment.

4.3 Galvanic Corrosion Considerations

4.3.1 Internal Corrosion Resistance

Internal corrosion is primarily caused by galvanic coupling of titanium to a ferrous material in electrically conductive fluid. Corrosive materials are discussed in 4.10.3. Internal galvanic coupling can occur at elevated H₂S levels, free water levels, and temperatures. If these conditions do exist, the operator must either electrically isolate the titanium section with an insulated material or insert a galvanically compatible joint between the titanium and steel section. If a galvanically compatible joint is used, inhibitors may be used in the riser fluid to prevent hydrogen embrittlement inside of the titanium riser.

NOTE There are instances in which inhibitors are utilized for specific group of acids.

4.3.2 External Corrosion Protection

External corrosion protection shall be provided by appropriate materials selection, coating systems, and cathodic protection.

Grades 1, 2, 5, 9, and 23 are prone to corrosion when service temperature exceeds 85 °C (185 °F).

Examples of allowable coatings can be found in OTC 18624, listed in the Bibliography.

4.3.3 External Galvanic Reactions

Hydrogen embrittlement is potential mode of failure when titanium is mechanically and electrically coupled to steel or carbon steel. Hydrogen absorption caused by galvanic reactions of these two metals can lead to embrittlement in seawater environment.

Hydrogen damage of titanium alloys is manifested as loss of ductility and/or a reduction in the fracture toughness for crack propagation.

The connection between titanium and a cathodically protected steel structure can cause hydrogen embrittlement in the titanium structure.

To prevent embrittlement, there must be a nonconductive barrier between the two materials and/or electrical isolation of the titanium component. This precaution can lead to a number of benefits including:

- reduce risk of long-term hydrogen embrittlement in the titanium component,
- eliminate galvanic interactions between titanium and steel components,
- reduce the consumption rate of the sacrificial anodes coupled to the steel components.

4.3.4 Cathodic Corrosion Protection

Titanium alloys are safe from corrosion under -750 MV vs Ag/AgCl. Proper cathodic protection system shall be used. There are strategies to mitigate such corrosion.

The well intervention system shall have a cathodic protection system designed for the specified design life in accordance with API 17G.

Cathodic protection system design requires consideration of the external area of the equipment being protected. The equipment manufacturer shall be responsible for documenting the design basis of the cathodic protection system.

4.4 Fasteners

Closure bolting and critical bolting should be designed using the design verification requirements of API 17G. Bolt preload requirements should follow the guidelines of API 17D. Qualification, production, and documentation of bolting should meet the requirements of API 20F.

The general guidelines for design validation, as stated in 4.2.4, shall be used for titanium alloys.

The following precautions and measures should be taken when titanium alloy is used for fasteners.

- a) Creep limit of titanium alloys should be considered when using for fasteners, bolts, studs, and screws. Temperature and environment conditions have influence on creep strength.
- b) Hydrogen embrittlement of titanium alloy may occur if these alloys are galvanic coupled to certain active metals (e.g. carbon steel) in H_2S -containing aqueous media at temperatures above $80^\circ C$ ($176^\circ F$).
- c) Some titanium alloys may be susceptible to crevice corrosion and/or SCC in chloride environments.

4.5 Coatings

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Coating selection is outside the scope of this document but barrier coatings should be nonconductive, tough, and durable. This has been achieved by employing well bonded rubber to the titanium. These coatings are normally 3 mm to 5 mm thick but may be thicker in areas where abrasion is expected. They also readily bond

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to weight coatings and thermal insulation. Suitable rubbers should be selected, together with their maximum operating temperatures.

4.6 Metallic Seal Ring

Titanium Grades 1, 2, 12, and 19 should be used for titanium seal ring applications.

4.7 Hardfacing and Metallic and Nonmetallic Coating

Any coating metallic or nonmetallic used for application defined in 4.5 shall be qualified. Coating for corrosion resistance shall be qualified in actual environment and temperature range.

4.8 Ductility, Toughness, and Hardness

To ensure ductile failure and avoid hydrogen embrittlement, mechanical properties of titanium alloys shall meet the following requirements for base material, heat-affected zone, and weld metal.

- a) The tensile properties limitation for titanium alloys are specified in Table 1.
- b) Charpy impact testing is neither required nor valid for titanium alloys.
- c) Toughness of the alloy shall be evaluated with fracture mechanics testing. The alloys may be evaluated by J_{IC} , K_{IC} , or crack tip opening displacement (CTOD) per ASTM E399. The requirement shall be specified by the purchaser using design criteria.
- d) The maximum hardness to avoid hydrogen embrittlement under sour service and cathodic protection shall be limited by ANSI/NACE MR0175/ISO 15156.

4.9 Fracture Mechanics

4.9.1 General

Fracture mechanics design method for fatigue assessment shall be based on ASME *BPVC, Section VIII, Division 3*. Fracture mechanics is an acceptable alternative to elastic-plastic analysis when designing titanium components.

The fracture mechanics testing for titanium alloys and weldment shall be qualified and assessed as in 4.2.5.

The minimum fracture toughness value of CTOD, K_{IC} , or J_{IC} shall be based on design requirements depending on actual operating temperature, YS, material thickness, and expected environment.

Fracture mechanics criteria shall be based on fracture toughness test parameters such as CTOD, K_{IC} , or J_{IC} per ASTM E399, and/or KJ or K1J per ASTM E1820. Note that these high-strength titanium alloy riser components are often insufficiently thick to achieve valid K_{IC} values (cannot meet plane-strain criteria) per ASTM E399 specification requirements. CTOD (ASTM E1290) and KQ (ASTM E399) tend to be highly dependent on test specimen thickness, such that these toughness values increase with increasing specimen thickness in these plastic alloys. Therefore, toughness specimen thickness should be maximized where possible and/or utilize elastic-plastic fracture-mechanics-based test values (e.g. KEE, KJ, JC) for more representative toughness results.

Fracture mechanics shall be applied to titanium stress joints and riser components.

4.9.2 Fatigue Crack Growth Rate

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When possible, fatigue crack growth data should be evaluated from test results in the intended environment since this can greatly affect the fatigue crack growth rate. Cyclic fatigue crack growth data, da/dN vs ΔK ,

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including threshold K_{th} and environmentally assisted fracture toughness KIEAC, may be determined by testing per ASTM E647 or other applicable standards, or by data that are determined to be as conservative as or more conservative than the actual material properties in the defined environment and loading conditions. Cyclic crack growth material properties for fracture mechanics design are defined in API 579-1/ASME FFS-1 or BS 7910.

4.9.3 Environmental Effects

Environmental effects shall be taken into consideration when modeling fracture mechanics and effective life cycle. Section 4.10.3 contains environmental considerations.

4.10 Titanium Selection

4.10.1 General

Titanium selection shall take into account internal and external fluids, loads, temperature, and possible failure modes. The selection of materials shall ensure that the requirements are met for all components in the subsea well intervention system.

Pressure-containing, pressure-controlling, and/or primary load bearing components shall not be manufactured from cast materials.

Weld repair of pipes, forgings, and fasteners is prohibited.

It shall be the responsibility of the end user to ensure that material specified and material properties are suitable for the operating conditions.

Titanium Grades 23, 25, 28, and 29 are primary used for tension stress joint, slick joint, and tension ring. Other suitable titanium alloys may be used for other components as described in Table 1 with due qualification.

4.10.2 Sour Service

Table 1 indicates which grades are suitable for sour service conditions. These grades shall be used where ANSI/NACE MR0175/ISO 15156 standard is required.

It shall be the responsibility of the manufacturer to ensure materials for sour service are in compliance with ANSI/NACE MR0175/ISO 15156. Metallic material exposed to H_2S -containing environments that do not comply with ANSI/NACE MR0175/ISO 15156 shall be documented and presented to the end user or third-party integrator for approval.

4.10.3 Environmental Conditions

4.10.3.1 General

Titanium alloys can suffer from mass loss corrosion in certain acidizing fluids and in methanol. Care must be taken to verify compatibility of the chosen titanium alloy in such environments.

4.10.3.2 Methanol

Methanol is often used in hydrate dissolution subsea. Dry methanol (99 %) should never contact titanium alloy metal surfaces to avoid SCC problems. Water is a highly effective inhibitor. To prevent damage to the titanium, the minimum water percentages shall be in accordance with DNV RP-F201.

4.10.3.3 Hydrofluoric Acid

Hydrofluoric acid (HF) reacts with titanium; therefore, HF should not be used with bare titanium surfaces. Inhibitors or coatings shall be used to prevent critical damage to the titanium tubular.

4.10.3.4 Hydrochloric Acid

Hydrochloric acid (HCl) also reacts with titanium; therefore, HCl should not be used with bare titanium surfaces. Inhibitors or coatings may be used to prevent critical damage to the titanium tubular.

4.10.4 Material Considerations

4.10.4.1 Stress-Strain Considerations

It is highly likely that titanium will be coupled with a dissimilar metal in subsea application. For this reason, titanium components shall be designed in such a way that in accidental loading state all components shall maintain structural integrity. Annex A, Figure A.1 shows the stress-strain curve for both steel and titanium. The YS of titanium is close to its ultimate TS, while there is a range of plasticity between the yield and ultimate TS in steel.

4.10.4.2 Coefficient of Thermal Expansion

The relatively low thermal expansion coefficient of titanium must be taken into account during the design process, as it is roughly half that of steel. Therefore, the direct substitution of titanium into a design where thermal expansion has not been accounted for will be invalid.

4.10.4.3 Ductile-Brittle Transition

High-strength titanium alloys do not exhibit the classic "ductile-to-brittle" transition behavior as service temperature decreases. A gradual, monotonic increase in alloy strength and modulus, along with a subtle decrease in ductility and toughness, occur with decreasing temperatures down to the cryogenic range.

4.10.4.4 Wear Resistance

Titanium alloys show poor wear resistance in systems that involve rotating and sliding components. Compared to a steel-steel couple, the wear of titanium-titanium was around 15 % higher.

4.11 Manufacturing and Fabrication Requirements

4.11.1 General

The guidelines and requirements as stated in 4.2 shall be followed for qualification of material and manufactures, material specification, limitations, manufacturing procedure, and qualification.

Fabrication and manufacturing requirements and standards can be found in API 17G. Depending on the manufacturing process, stress can be introduced that could negatively affect the performance of the piece. Design features normally found in steel, such as undercuts, that depend on a degree of localized yielding are not acceptable.

Due to a buildup of alpha case on both the exterior and interior of the tubular surfaces, the alpha case must be either physically or chemically removed. If the alpha case is not removed, it can lead to cracking or early failure of the equipment. Chemical milling is preferred as it removes the least material, subsequently increasing the usable life of the equipment.

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Hydride embrittlement can occur during both fabrication and field use. Gaseous hydrogen and hydrogen introduced cathodically can cause embrittlement. Temperature, pH, and titanium grade must all be taken into account during design to avoid hydride embrittlement.

4.11.2 Weldments

Gas tungsten arc welding is the preferred method for welding titanium intervention equipment. Inspection of weldments can be carried out the same way as traditional ferrous materials, with the exception of magnetic particle, as titanium is nonmagnetic.

More details on welding can be found in DNV RP-F201.

4.12 Nondestructive Testing

4.12.1 General

All components for subsea intervention system will require nondestructive testing (NDT). The requirements and qualification shall be per API 17G. The NDT shall be performed in accordance with the written procedure and quality plan. When possible, 100 % volume shall be inspected.

NDT shall be performed using a combination of methods capable of detecting surface and subsurface imperfections that would classify the material being inspected as rejectable.

All NDT of forgings and weldments shall be performed in accordance with written defined procedures and acceptance criteria.

All NDT shall be detailed in a test report documenting the techniques and parameters of the test. The report shall contain sufficient information such that the testing can be reliably repeated.

4.12.2 Weldments

All fatigue critical weldments shall be subjected to 100 % high definition radiography in addition to ultrasonic inspection.

The weldments with higher dynamic loadings shall be identified, and extended NDT of these welds shall be considered. Extended NDT can take place in the form of spot checks performed by other qualified operator.

5 Aluminum Group

5.1 Objective

5.1.1 General

This section provides guidelines and requirements for use of aluminum alloys for subsea intervention systems. Aluminum provides a low modulus, low weight system as compared to steel systems. This section is a gap analysis to the main document and an informative tool in selecting the proper grade of aluminum per project requirements.

5.1.2 Application

Aluminum alloys are successfully used in low-pressure, <10 ksi, service with proper design and manufacturing. Determination of a specific alloy shall be designated per project requirements.

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The design basis for aluminum application shall be API 17TR8, where fracture mechanics play an important role, irrespective of the load or pressure.

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The essential requirements in selecting manufacturing, quality controls, and certification are outlined in 5.2.

Aluminum alloys shall be corrosion resistant, fulfilling ANSI/NACE MR0175/ISO 15156 requirements.

Recommended alloys for subsea intervention can be found in Table 2. These alloys were selected on the basis of YS, minimum 50 ksi. Application of an aluminum alloy with YS below 50 ksi may be viable under proper engineering practices and design criteria.

Typical use of aluminum alloys is riser components and other tubular products. Use of aluminum in seals is not recommended due to potential localized yielding of the material.

Table 2—Aluminum Alloys

Alloy and Temper ^a	UNS Number	Yield Strength ^b ksi	Tensile Strength ^b ksi
2014-T6, T651 *	A92014	58	70
2024-T3 *	A92024	50	70
2024-T361	A92024	57	72
2124-T851	A92124	64	70
2219-T81, T851	A92219	51	66
2219-T87 *	A92219	57	69
2618-T61	A92618	54	64
5056-H18 *	A95056	59	63
5056-H38	A95056	50	60
6066-T6, T651	A96066	52	57
6070-T6	A96070	51	55
7005-T53L	A97005	44	50
7049-T73	A97049	65	75
7049-T7352	A97049	63	75
7050-T73510, T73511	A97050	63	72
7050-T7651 *	A97050	71	80
7075-T6 & T651 *	A97075	73	83
7050-T7451	A97050	68	76
* Denotes commonly used alloy.			
^a Some aluminum alloys have aging temperatures below 300 °F.			
^b Minimum values.			

5.2 Design

5.2.1 General

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Physical properties such as modulus of elasticity, thermal expansion coefficient, thermal conductivity, and thermal diffusivity should be considered at maximum design temperature.

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Creep propagation is a design consideration when working with aluminum alloys. A project shall take elevated temperatures and the associated reduction in material specified minimum yield strength (S_y) into consideration as part of the design. Working stresses shall follow design stress intensity/material specified minimum yield strength (S_m/S_y) ratio guidelines, with adjustments based upon operating temperature per ASME BPVC, Section VIII, Division 2, Part D (Materials) to prevent creep propagation.

5.2.2 Design Considerations

Due to the differences in material properties between steel and aluminum, as stated in 5.9.4, one shall take into consideration the following items when using aluminum in subsea application:

- FEA design review,
- effects of YS/TS ratio,
- modulus of elasticity,
- surface stresses (residual/applied),
- localized plasticity (yielding),
- material substitutions (with analysis),
- coefficient of thermal expansion,
- fatigue analysis.

Failure to address these issues and direct substitution with another material could result in catastrophic failure.

5.2.3 Prevention of Creep

Creep propagation is a design consideration when working with aluminum alloys, including working at ambient temperatures at high loads. Allowable operating temperature ranges shall be defined and documented. Changes to SMYS due to temperature effects shall be included in equipment design documentation as a part of any stress calculations.

Option 1—Working stresses shall remain below 45 % SMYS at operating temperature per ASME BPVC, Section VIII, Division 2 to prevent creep propagation.

Option 2—Manufacturer can test the material(s) specifically for the intended application and apply the following rules to define allowable stress and prevent creep. The normal design stress shall not exceed the lowest of the following:

- 67 % of SMYS;
- 100 % of the average stress required to produce a creep rate of $0.01\%/1000\text{ hr}^a$, when tested at or above design temperature.

NOTE Extreme and accidental load limits will remain as defined within API 17G, with their relative position with respect to the normal load limit.

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⁹ ASME BPVC, Section II, Part D, Appendix 1.

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5.2.4 FEA Design Verification

Design verification shall be performed to ensure that the aluminum equipment design conforms to applicable functional specifications and serviceability criteria. Design validation shall be performed to ensure that aluminum equipment protects against failure modes identified for the specific equipment. The impact of the following items shall be evaluated as part of design verification and validation:

- 1) global plastic collapse,
- 2) local failure due to excessive strain (local strain limit damage),
- 3) ratcheting effects,
- 4) plastic collapse under the hydrostatic test condition,
- 5) fatigue assessment (life-cycle estimation).

The loads obtained from the functional specifications form the design basis for the aluminum equipment and shall include the specified operating pressure, temperature, and external loads as well as the corresponding cyclic loadings (loading histogram) for significant events that are applied to the equipment.

NOTE Regulations from a jurisdictional authority may impose additional or different requirements for a particular service environment.

Where API product standards exist with specific design factors for aluminum equipment, these factors should be satisfied as a minimum.

5.2.5 Validation

The design validation process is required to demonstrate that the equipment maintains the mechanical integrity and functionality/operability relative to its functional specifications.

Design validation should have the following components.

- 1) Validation (testing/qualification) of a component and/or system under development.
- 2) Validation of the design method: Model predictions (i.e. stress or thermal FEA, fatigue analysis, fracture mechanics, etc.) should be validated by measurements and testing. Historical validation processes can remain valid if they can be documented, demonstrated as technically sound, and meet the equipment design requirements and service conditions. Guidance for validation of FEA is provided in ASME V&V 10-2019, *Standard for Verification and Validation in Computational Solid Mechanics*.
- 3) Validation of materials used for the design: Material properties, service and application limits used in the analyses should be based on test data or recognized sources/literature. Degradation mechanisms that should be considered in the material validation process may include, but not be limited to:
 - temperature;
 - corrosion;
 - fatigue;
 - SCC;

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- erosion/corrosion; and
- other corrosion mechanisms, etc.

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5.2.6 Design Life

Design life and service life shall be specified; see API 17G, Annex F. If the service life has not been specified, a minimum of five years shall be assumed.

5.2.7 FEA Design

FEA analysis should be done on aluminum subsea equipment. Accidental loading should be applied for worst-case scenario. No amount of localized yielding shall be deemed acceptable.

5.3 Galvanic Corrosion Considerations

5.3.1 Internal Corrosion Resistance

Internal corrosion can be caused by both galvanic coupling and reactions with workover fluid.

Elevated chloride levels, free water levels, and temperature can increase the rate of corrosion due to galvanic coupling. If these conditions do exist, the operator must either isolate the aluminum section with an electrically insulated material or insert a galvanically compatible joint between the aluminum and base metal. Appropriate inhibitors must be used to protect the base metal.

Environmental factors, outlined in 5.9.3, may cause internal corrosion in aluminum riser systems. Chemical isolation using nonconductive coatings such as polymers or tar may prevent internal corrosion. A thick anodized layer may also be applied to the inner diameter to increase protection.

5.3.2 External Corrosion Protection

External corrosion protection shall be provided by appropriate materials selection, coating systems, and cathodic protection. Subsea corrosion characteristics shall be used when testing corrosion.

5.3.3 Potential Galvanic Reactions

Hydrogen embrittlement is of little concern for aluminum components in a subsea riser system. Galvanic coupling presents a much larger risk due to the reactivity with steel.

To prevent embrittlement, there must be a nonconductive barrier between the two materials and/or electrical isolation of the aluminum component. This precaution can lead to a number of benefits including:

- reduce risk of long-term hydrogen embrittlement in the steel component,
- eliminate galvanic interactions between aluminum and steel components,
- reduce the consumption rate of the sacrificial anodes coupled to the steel components.

5.3.4 Cathodic Corrosion Protection

The well intervention system shall have a cathodic protection system designed for the specified design life in accordance with DNV-RP-B401/NACE SP0176.

Cathodic protection system design requires consideration of the external area of the equipment being protected. The equipment manufacturer shall be responsible for documenting the design basis of the cathodic protection system.

5.4 Coatings

Coating systems are outside the scope of this document, but some material limitations apply. Coatings requiring fluid with pH levels above 9.5 shall not be used. Coatings, both internal and external, requiring heat treatment above 200 °F for extended time should not be used as these treatments can alter the material properties of the aluminum.

Coatings should be nonconductive and may increase in thickness in areas where elevated corrosion rates are expected to occur.

Anodization may also be used to increase the oxide film protecting the riser. Increases in the oxide thickness allow for more corrosion to occur before contacting the alloy directly.

5.5 Hardfacing and Metallic and Nonmetallic Coating

No hardfacing or metallic coatings shall be used on aluminum riser systems. Nonmetallic coatings used for subsea application as defined in 5.4 shall be qualified. Coating for corrosion resistance shall be qualified in expected environment and conditions.

5.6 Valves and Actuators

Aluminum shall not be used for critical components for both valves and actuators. Items such as housings may be constructed of aluminum with proper qualification.

5.7 Ductility, Toughness, and Hardness

To ensure ductile failure, material properties shall meet the following requirements for the base material, heat-affected zone, and weld metal.

- a) The tensile properties limitation for aluminum alloys are specified in Table 2.
- b) Charpy impact testing is neither required nor valid for aluminum alloys.
- c) Toughness of the alloy shall be evaluated with fracture mechanics testing. The alloys may be evaluated by J_{1C} , K_{1C} , or CTOD per ASTM E399. The requirement shall be specified by the purchaser using design criteria. Reduction of area is not required for aluminum alloys.
- d) All corrosion properties shall meet ANSI/NACE MR0175/ISO 15156 requirements.

5.8 Fracture Mechanics

5.8.1 General

Fracture mechanics design method for fatigue assessment shall be based on ASME *BPVC, Section VIII, Division 3*. Elastic-plastic modeling must be used when dealing with aluminum alloys.

The minimum fracture toughness value of CTOD shall be based on design requirements depending on actual operating temperature, YS, and material thickness.

Fracture mechanics criteria shall be based on fracture toughness test parameters such as KQ or K_{1C} per ASTM E399 and/or KJ or K1J per ASTM E1820. CTOD (ASTM E1290) and KQ (ASTM E399) tend to be highly dependent on test specimen thickness, such that these toughness values increase with increasing specimen thickness in these plastic alloys. Therefore, toughness specimen thickness should be maximized

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where possible and/or utilize elastic-plastic fracture-mechanics-based test values (e.g. KEE, KJ, JC) for more representative toughness results.

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Fracture mechanics shall be applied to aluminum stress joints and riser components.

5.8.2 Fatigue Crack Growth Rate

When possible, fatigue crack growth data should be evaluated from test results in the intended environment since this can greatly affect the fatigue crack growth rate. Cyclic fatigue crack growth data, da/dN vs ΔK , including threshold K_{th} and environmentally assisted fracture toughness KIEAC, may be determined by testing or by data that are determined to be as conservative as or more conservative than the material properties determined from testing per ASTM E647 or other applicable standards in the defined environment and loading conditions. Cyclic crack growth material properties for fracture mechanics design are defined in API 579-1/ASME FFS-1 or BS 7910.

5.8.3 Environmental Effects

Environmental effects shall be taken into consideration when modeling fracture mechanics and effective life cycle. Section 5.9.3 contains environmental considerations.

5.9 Aluminum Selection

5.9.1 General

Aluminum selection shall take into account internal and external fluids, loads, temperature, and possible failure modes. The selection of materials shall ensure that the requirements are considered for all components in the subsea well intervention system.

Pressure-containing, pressure-controlling, and/or primary load bearing components shall not be manufactured from cast materials.

Weld repair of pipes and forgings is prohibited.

It shall be the responsibility of the end user to ensure that material specified and material properties are suitable for the operating conditions.

Suitable alloys can be found in Table 2 with due qualification.

5.9.2 Sour Service

Aluminum alloys may be used as an alternative to steel in high H_2S -containing fluids. Fluid with sufficient electrolyte and significant H_2S concentration will show a reduction in pitting corrosion.

Design specifications shall meet ANSI/NACE MR0175/ISO 15156 standards. When exposed to H_2S -containing environments, metallic materials that do not comply with ANSI/NACE MR0175/ISO 15156 shall be documented and presented to the end user or third-party integrator for approval.

5.9.3 Environmental Conditions

5.9.3.1 pH

At pH levels between 7.0 and 9.5 corrosion rates are insignificant without substantial chloride concentration. Environments with pH levels above 10.5 will exhibit rapid corrosion rates.

5.9.3.2 Temperature

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Aluminum riser systems shall not be subjected to environments exceeding 300 °F. At temperatures above 250 °F, special design and operation considerations must be made to account for material properties at these elevated temperatures. Refer to Table 2 for acceptable alloys for riser applications.

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Aluminum's material properties are permanently degraded by exposure to elevated temperatures. Time at temperature will determine the magnitude of the damage.

5.9.3.3 Erosion Corrosion

Considerations must be made if using fluid additives that may be abrasive to the riser system. Erosion corrosion is aided by large solids content and turbulent flows. In this environment, the protective aluminum oxide layer is damaged, leading to faster corrosion rates and ultimately failure of the equipment.

5.9.3.4 Mercury

The presence of mercury results in a chemical reaction that has catastrophic effects on aluminum.

5.9.4 Material Considerations

5.9.4.1 Stress-Strain Considerations

It is highly likely that aluminum will be coupled with a dissimilar metal in subsea application. For this reason, aluminum components shall be designed in such a way that in an accidental loading state all components shall maintain structural integrity. It is important to note that aluminum TS is also its ultimate strength, whereas with steel there is a range of plasticity before ultimate tensile stress.

5.9.4.2 Coefficient of Thermal Expansion

Aluminum alloys have a much larger coefficient of thermal expansion as compared to steel. Therefore, direct substitutions into steel systems are highly discouraged as dissimilarity in expansion may induce unnecessary loads.

5.9.4.3 Ductile-Brittle Transition

Aluminum alloys do not exhibit the classic "ductile-to-brittle" transition behavior. As service temperature decreases, aluminum alloys display a slight increase in alloy ductility and toughness with decreasing temperatures.

5.9.4.4 Wear Resistance

Aluminum alloys exhibit hardness substantially less than steel and will wear at a higher rate as compared to a steel system.

5.9.4.5 High Temperature Effects

Irreversible changes in aluminum's material properties occur at extended times and elevated temperatures that will not return at ambient levels.

5.10 Manufacturing Requirements

5.10.1 General

The guidelines and requirements stated in 5.2 shall be followed for qualification of material specification, limitations, manufacturing procedure, and qualification.

Fabrication and manufacturing requirements and standards can be found in 5.2. Depending on the manufacturing process, stress can be introduced that could negatively affect the performance of the piece. Design features normally found in steel, such as undercuts, that depend on a degree of localized yielding are

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not acceptable.

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5.10.2 Weldments

Gas shielded arc welding is the preferred method for welding aluminum intervention equipment. Inspection of weldments can be carried out the same way as traditional ferrous materials, with the exception of magnetic particle as aluminum is nonmagnetic.

5.11 Nondestructive Testing

5.11.1 General

All components for subsea intervention system will require NDT. The requirements and qualification shall be per API 17G. The NDT shall be performed in accordance with the written procedure and quality plan. When possible, 100 % volume shall be inspected.

NDT shall be performed using a combination of methods capable of detecting surface and subsurface imperfections that would classify the material being inspected as rejectable.

All NDT of forgings and weldments shall be performed in accordance with written defined procedures and acceptance criteria.

All NDT shall be detailed in a test report documenting the techniques and parameters of the test. The report shall contain sufficient information such that the testing can be reliably repeated.

5.11.2 Weldments

All fatigue critical weldments shall be subjected to 100 % high definition radiography in addition to ultrasonic inspection.

The weldments with higher dynamic loadings shall be identified, and extended NDT of these welds shall be considered. Extended NDT can take place in the form of spot checks performed by other qualified operator.

6. Nickle (NEW SECTION)

6.1. Objective

6.1.1. General

Precipitation Hardened Nickel Alloys (PHNA) have been used extensively in high strength, severe service environments as pressure containing and pressure controlling equipment. Section 6 provides guidelines and requirements for the use of precipitation hardened nickel alloys for subsea intervention systems. Nickel grades provide extremely high strength, high temperature resistance, and high corrosion resistance. This section is a gap analysis to the main document and an informative tool in selecting the proper nickel alloy per project requirements.

The guidelines and requirements as stated in section 6.2 shall be followed for the qualification of material and manufactures, material specification, limitations, manufacturing procedure and qualification.

Fabrication and manufacturing requirements and standards can be found in API 17G. Depending on the manufacturing process, stress can be introduced that could negatively affect the performance of the piece. Design features normally found in steel, such as undercuts, that depend on a degree of localized yielding are not acceptable.

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Hydrogen embrittlement can occur during both fabrication and field use. Gaseous hydrogen and hydrogen introduced cathodically can cause embrittlement. Steps to prevent occurrences that facilitate hydrogen embrittlement are discussed in 6.3. The guidelines and requirements as stated in section 6.2 shall be followed for qualification of material and manufacturers, material specifications, limitations, and manufacturing procedures.

6.1.2. Application

When nickel alloys are used in subsea intervention, proper design shall be considered, along with proper alloy selection and manufacturing parameters.

The requirements for manufacturing and quality control are outlined in API 6A CRA.

Typically, the use of nickel alloys is for valves, crossovers, stress joints, fasteners and seal rings.

Table 1, contains a listing from API 6A CRA of precipitation hardened nickel alloys for use in H₂S service, fulfilling NACE (AMPP) requirements and which shall be designated for subsea well intervention systems. However, neither NACE (AMPP) nor API 6A CRA provide specific guidance regarding corrosion testing of all in situ well conditions. These specific applications shall be addressed during the design stages to determine the appropriate alloy(s) for use. Qualification testing of these alloys should be as agreed with the end user.

There may be occasions where higher strength is not required (compressible seals, etc.) but corrosion resistance is still desirable. In these cases, solid solution nickel alloys may be specified. Alloys such as 625 (UNS N06625), C-276 (UNS N10276) are acceptable for use in these applications subject to approval by the end user.

6.2. Design

Table 1 - API 6CRA Precipitation Hardened Nickel Alloy Grades for H₂S Service

Common Alloy Designation	UNS Number ^a	Yield Strength ^b (ksi)	Tensile Strength ^b (ksi)
625 120K	N06625	120	
716 120K	N07716	120	150
716 140K	N07716	140	165
718 120K	N07718	120	150
718 140K	N07718	140	165
718 150K	N07718	150	175
725 120K	N07725	120	150
925 110K	N09925	110	140
935 110K	N09935	110	140
945 125K	N09945	125	150
946 140K	N09946	140	165
946 150K	N09946	150	170
946 160K	N09946	160	180
955 120K	N09955	120	150
955 140K	N09955	140	165
^{a)} Unified Numbering System (UNS) ^{b)} Minimum Values			

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6.2.1. General

Physical properties such as modulus of elasticity, thermal expansion coefficient, thermal conductivity and thermal diffusivity should be considered at both minimum and maximum operating temperatures.

The maximum hardness of different grades shall comply with NACE MR0175 / ISO 15156-3

6.2.2. Material Property Design Considerations

Due to the differences in material properties between steel and nickel one must take into consideration the potential for hydrogen embrittlement due to dissimilar metals when using nickel in subsea applications.

Failure to address these issues and direct substitution with another material may result in catastrophic failure.

Refer to IOGP 679 for guidance on the selection of PHNA grades with respect to hydrogen embrittlement performance.

Weld repair of any component or raw material is prohibited.

6.2.3. FEA Design Verification

The objective for design verification is to confirm that the nickel equipment design is in compliance with its functional specifications and serviceability criteria, and the equipment has adequate protection against failure modes identified for specified equipment:

- a) Global plastic collapse
- b) Local failure due to excessive strain (local strain limit damage)
- c) Ratcheting effects
- d) Plastic collapse under the hydrostatic test conditions
- e) Fatigue assessment (life-cycle estimation)

The loads obtained from the functional specifications form the design basis for the nickel equipment, and shall include the applicable operating pressure, temperature, and external loads as well as the corresponding cyclic loadings (loading histogram) for significant events that are applied to the equipment.

It is necessary that users of this document be aware of regulations from a jurisdictional authority that may impose additional or different requirements which better suit the demands of a particular service environment. Where API product standards exist with specific design factors for nickel equipment, these factors should be satisfied as a minimum. This document provides additional considerations in nickel equipment designs.

6.2.4. Validation

The design validation process is required to demonstrate that the equipment maintains the mechanical integrity and functionality / operability relative to its functional specifications.

Design validation is defined in API 17G and Q1, and it should have the following components:

- Validation of materials used for the design: Material properties, service and application limits used in the analysis should be based on test data or recognized sources / literature.
- Degradation mechanisms that should be considered in the material validation process. These may include, but are not be limited to:
- Temperature
- Corrosion
- Fatigue

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- SCC, SSC and hydrogen embrittlement
- HIC
- Erosion/corrosion, and
- Other corrosion mechanisms.

6.2.5. Design Life

Design life and service life shall be specified, see API 17G Annex F. If the service life has not been specified, a minimum of five years shall be assumed.

6.2.6. FEA Design

FEA analysis shall be done on nickel subsea equipment as per design requirements in API 17G.

Critical defect size should be accounted for during FEA analysis. Critical defect size shall be determined for specific equipment.

6.3. Corrosion Considerations For Nickel Alloys

While general corrosion of nickel alloys does not occur when materials are properly selected, galvanic corrosion can be a concern for several reasons. First, connection to nickel may cause corrosion of steel or less noble alloyed components which are lower on the galvanic series. Second, galvanic corrosion generates hydrogen at the cathode, which is the nickel alloy. Under certain stress and environmental conditions, this hydrogen generation may produce hydrogen embrittlement in susceptible grades.

Proper equipment design to mitigate the risk of galvanic corrosion may include:

- alloy selection
- corrosion mitigation methods
- isolation or insulation of joints
- coatings, or other methods.

Section 6.3.3 has further information on galvanic reactions.

6.3.1. Internal Corrosion Resistance

General corrosion of nickel alloys is not typical in standard subsea environments. Pitting, however, can occur, especially in crevice areas. Pitting is especially a concern for seal surfaces or areas in high tension. Proper material selection should be undertaken to avoid pitting in critical areas.

6.3.2. Potential Galvanic Reactions

Hydrogen embrittlement is a potential mode of failure when nickel alloy is mechanically and electrically coupled to steel or alloy steel. Hydrogen absorption caused by galvanic reactions of these two metals can lead to embrittlement.

Hydrogen damage of nickel alloys is manifested as loss of ductility and/or a reduction in the stress-intensity threshold for crack propagation.

The galvanic connection between nickel and a cathodically-protected steel structure can cause hydrogen embrittlement in the nickel components.

To prevent embrittlement there must be a non-conductive barrier between the two materials and/or electrical isolation of the nickel component. This precaution can lead to a number of benefits including:

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- Reduced risk of long-term hydrogen embrittlement in the nickel component.
- Elimination of galvanic corrosion between nickel and steel components.
- Reduced consumption rate of the sacrificial anodes coupled to the steel components.

6.3.3. Environmental Conditions

For methanol and acid service such as HF or HCL, nickel alloys have been successfully employed. However, certain combinations of acids, temperatures, accelerants, inhibitors and process fluids may not be suitable. Each individual methanol or acid provider should provide documentation that their particular proprietary blend is suitable for the materials it is designed to contact. Where this data is not available, additional testing may be required.

6.4. Fasteners

Closure bolting and critical bolting shall be designed using the design verification requirements of API 17D. Bolt preload requirements should follow the guidelines of API 17D. Qualification, production and documentation of bolting should meet the requirements of API 20F.

The general guidelines for design validation, applicable to nickel alloys as stated in 6.2.4, shall be used.

The following precautions and measures shall be taken when nickel alloy is used for fasteners:

- a) Creep limit of nickel alloys should be considered when used for fasteners, bolts, studs and screws. Temperature and environmental conditions have influence on creep strength.
- b) Hydrogen embrittlement of nickel alloys may occur if these alloys are galvanically coupled to certain active metals (e.g. carbon steel)
- c) Some nickel alloys may be susceptible to pitting, crevice corrosion, SCC and /or SSC in high chloride or low PH environments.

6.5. Hard Facing, Metallic and Non-Metallic Coating

Coating selection is outside the scope of this document, but barrier coatings should be non- conductive, tough, and durable.

Any coating, metallic or non-metallic shall be qualified. Coatings specifically applied for corrosion resistance shall be qualified in actual environment and temperature range, however, nickel alloys are rarely coated solely for corrosion resistance.

6.6. Fracture Mechanics

The toughness of the alloy shall be evaluated with fracture mechanics testing. The alloys may be evaluated by J_{1C} or CTOD per ASTM E1820. The requirement shall be specified by the purchaser using design criteria.

Fracture mechanics design method for fatigue assessment shall be based on ASME BPVC Section VIII, Division 3.

The fracture mechanics testing for nickel alloys and weldments shall be qualified and assessed as in Section 6.2.5.

The minimum fracture toughness value of CTOD shall be based on design requirements depending on actual operating temperature, yield strength and material thickness.

Fracture mechanics criteria shall be based on fracture toughness test parameters such as KEE per ASTM E992 and/or J_{1C} , K_J or K_{J1C} per ASTM E1820. CTOD (ASTM E1820) and K_Q (ASTM E399) tend to be highly dependent on test specimen thickness, such that these toughness values increase with increasing specimen

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thickness in these plastic alloys. Therefore, toughness specimen thickness should be maximized where possible, and/or utilize elastic-plastic fracture mechanics-based test values (e.g., K_{EE} , K_J , J_c) for more representative toughness results.

Guidance on fracture toughness testing is detailed in API 17TRD, Section D.7 (Appendix D) and more specifically, Table D.3 which provides information for conducting J-R curves with loading parameters to use for both inert and environmental testing.

6.6.1. Fatigue Crack Growth Rate

When possible, fatigue crack growth data should be evaluated from test results in the intended environment since this can greatly affect the fatigue crack growth rate. Cyclic fatigue crack growth data, da/dN vs. ΔK , including threshold K_{th} and environmentally assisted fracture toughness K_{IEAC} , may be determined by testing or by data that are determined to be as conservative as or more conservative than the actual material properties in the defined environment and loading conditions. Cyclic crack growth material properties for FM design are defined in API 579-1/ASME FFS-1, or BS 7910.

Refer to API 17TR8 Section D.8 (Appendix D) for guidance on fatigue crack growth rate testing, which includes procedures for generating new design fatigue curves and also validating existing curves in industry standards for both inert and corrosive environments.

6.6.2. Environmental Effects

Environmental effects must be taken into consideration when modelling fracture mechanics and effective life cycle. Section 6.10.3 contains environmental considerations.

6.7. Manufacturing and Fabrication Requirements

6.7.1. General

For precipitation hardening (PH) nickel alloys, manufacturing process and quality control shall comply with API 6ACRA.

Fabrication and manufacturing requirements and standards can be found in API 17G. Depending on the manufacturing process stress can be introduced that could negatively affect the performance of the piece. Design features normally found in steel, such as undercuts, that depend on a degree of localized yielding are not acceptable.

Hydrogen embrittlement can may occur during both fabrication and field use. Gaseous hydrogen and hydrogen introduced cathodically can cause embrittlement. Temperature, pH, and Environmental conditions, temperature, stress state, and nickel grade must all be taken into account during design to avoid hydride hydrogen embrittlement. See Section 6.3.3 for more information.

6.7.2. Weldments

GTAW (Gas Tungsten Arc Welding) is the preferred welding method for precipitation hardened nickel alloys. Electron beam welding has also been employed for nickel alloys in oil and gas service, but is limited to very small components.

Any welding for sour service shall comply with NACE MR0175 / ISO 15156 guidelines. Post weld heat treatment is not performed with PH nickel alloys unless part of an ageing cycle in order to restore strength, because PH nickel alloys lose strength at the weldment as a result of the welding process.

Any pressure containing welds or welds exposed to tensile loading shall be qualified by corrosion testing in the intended environment.

6.8. Non-Destructive Testing

6.8.1. General

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All components for subsea intervention systems will require non-destructive testing. The requirements and qualification shall be as per API 17G Clause 8.6. The NDT shall be performed in accordance with the written procedure and quality plan. When possible, 100% volume shall be inspected.

Non-destructive testing (NDT) shall be performed using a combination of methods capable of detecting surface and subsurface imperfections that would classify the material being inspected as rejectable.

All non-destructive testing of forgings and weldments shall be performed in accordance with written defined procedures and acceptance criteria.

All NDT shall be detailed in a test report documenting the techniques and parameters of the test. The report shall contain sufficient information such that the testing can be reliably repeated.

6.8.2. Weldments

All fatigue- critical weldments shall be subjected to 100% high-definition radiography in addition to ultrasonic inspection.

The weldments with higher dynamic loadings shall be identified, and extended NDT of these welds shall be considered. Extended NDT can take place in the form of spot checks performed by another qualified operator.

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Annex A (informative)

Figures

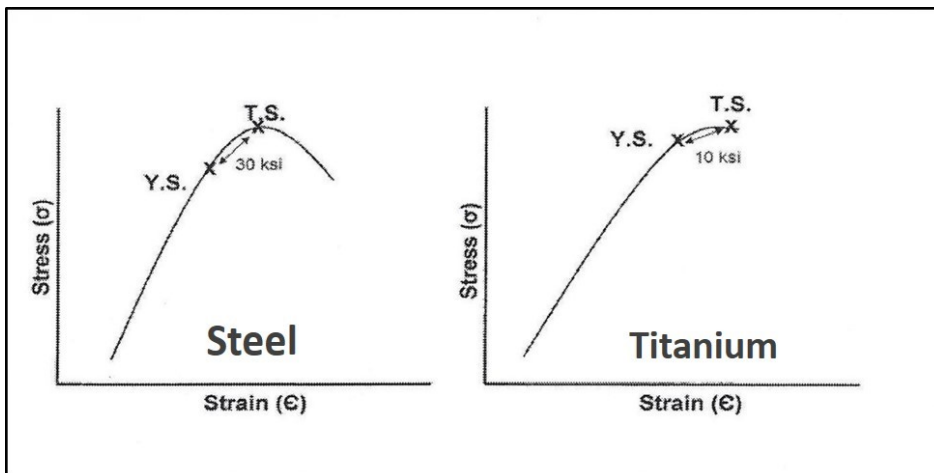


Figure A.1—Stress-Strain Curves of Steel and Titanium

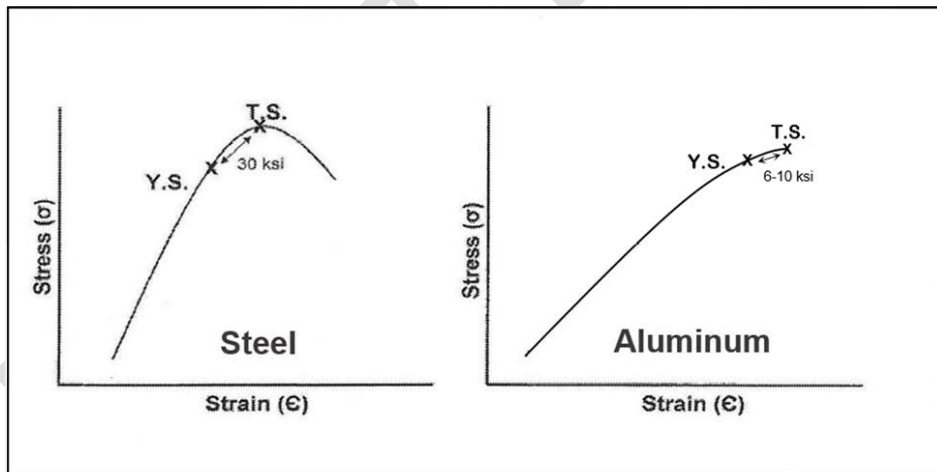


Figure A.2—Stress-Strain Curves of Steel and Aluminum

Figures are for information purposes only, are not to scale, and are not to be used for design. The general noteworthy comparisons relate to (1) the tighter difference between the TS and YS in both titanium and aluminum as compared to steel; (2) titanium and aluminum TSs are the point of fracture of the tensile specimen, unlike steel where there is further strain up to the point of fracture; and (3) the modulus of elasticity for titanium is almost half that of steel and for aluminum it is about one-third of the modulus of elasticity of steel. The modulus of elasticity is the slope of the linear portion of the stress-strain curve.

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BALLOT DRAFT

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Bibliography

- [1] API Specification 5CRA, *Specification for Corrosion-resistant Alloy Seamless Tubes for Use as Casing, Tubing, and Coupling Stock*
- [2] OTC 18624, "Experience and Guidance in the Use of Titanium Components in Steel Catenary Riser Systems"; C.F. Baxter, R.W. Schutz, C.S. Caldwell; OTC-18624-MS; Offshore Technology Conference; 30 April to 3 May 2007; Houston, TX
- [3] "Implement Russian Aluminum Drill Pipe and Retractable Drilling Bits into the USA," Department of Energy, Aquatic, Maurer Engineering, August 1999
- [4] ASME V&V 10-2019, *Standard for Verification and Validation in Computational Solid Mechanics*

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