Recommended Practice for Composite Lined Steel Tubular Goods

API RECOMMENDED PRACTICE 15CLT
FIRST EDITION, SEPTEMBER 2007

REAFFIRMED, OCTOBER 2013

AMERICAN PETROLEUM INSTITUTE

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Upstream Segment

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Suggested revisions are invited and should be submitted to the Standards Department, API, 1220 L Street, NW, Washington, D.C. 20005, standards@api.org.

Contents

Recommended Practice for Composite Lined Steel Tubular Goods

1 Scope

This recommended practice (RP) provides guidelines for the design, manufacture, qualification and application of composite lined carbon steel downhole tubing in the handling and transport of multiphase fluids, hydrocarbon gases, hydrocarbon liquids and water. The principles outlined in this RP also apply to line pipe applications.

Composite lined tubing typically consists of a fiber reinforced polymer liner within the steel host, providing protection of that steel host from corrosive attack. Both API and premium connections can be employed, typically using corrosion barrier rings to maintain corrosion resistance between ends of adjacent liners.

This document contains recommendations on material selection, product qualification, and definition of safety and design factors. Quality control tests, hydrostatic tests, dimensions, material properties, physical properties, and minimum performance requirements are included.

The RP applies to composite lined carbon steel for systems up to 10 in. (250 mm) diameter, operating at pressures up to 10,000 psi (69 MPa) and maximum temperatures of 300 °F (150 °C). The principles described in this document can easily be extended to apply to products being developed by manufacturers for application outside this range.

2 References

2.1 Normative References

This RP includes by specific reference within its text, either in total or in part, the most current issue of the following standards and industry documents:

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

API Specification 15HR, *High Pressure Fiberglass Line Pipe*

ASTM D 4745[1], *Standard Specification for Filled Compounds of Polytetrafluoroethylene (PTFE) Molding and Extrusion Materials*

ISO 2578[2], *Plastics—Determination of time-temperature limits after prolonged exposure to heat*

ISO 178, *Plastics—Determination of flexural properties*

ISO 13679, *Petroleum and natural gas industries—Procedures for testing casing and tubing connections*

ISO 11357-2, *Plastics—Differential scanning calorimetry (DSC)—Part 2: Determination of glass transition temperature*

ISO 15156 (Parts 1, 2, & 3), *Petroleum and natural gas industries—Materials for use in H_2S-containing environments in oil and gas production*

NACE MR0175 (IS0 15156 Parts 1, 2, & 3)[3], *Petroleum and natural gas industries—Materials for use in H_2S-containing environments in oil and gas production*

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[1]ASTM International, 100 Bar Harbor Drive, West Conshohocken, Pennsylvania 19428, www.astm.org.
[2]International Organization for Standardization, 1, ch. de la Voie-Creuse, Case postale 56, CH-1211, Geneva 20, Switzerland, www.iso.org.
[3]NACE International (formerly the National Association of Corrosion Engineers), 1440 South Creek Drive, Houston, Texas 77218-8340, www.nace.org.

2.2 Requirements

Requirements of other standards included by reference in this RP are essential to the safety and interchangeability of the equipment produced. Only standards listed in 2.1 are considered part of this RP. Documents (sub-tier) that are referenced by these standards are not considered part of this RP.

2.3 Equivalent Standards

Standards referenced in this RP may be replaced by other international or national standards that can be shown to meet or exceed the requirements of the referenced standard. Manufacturers who use other standards in lieu of standards referenced herein are responsible for documenting the equivalency of the standards. Where a standard is revised, the latest edition may be used on issue and shall become mandatory 6 months from the date of the revision.

3 Glossary

3.1 General Definitions

The manufacturer is the party that manufactures or supplies equipment and services to perform the duties specified by the purchaser.

The purchaser is the party that initiates the project and ultimately pays for its design and construction. The purchaser will generally specify the technical requirements. The purchaser may also appoint a third party to act on his behalf.

3.2 Abbreviations

CB	corrosion barrier
CRA	corrosion resistant alloy
FRP	fiber reinforced polymer
PTFE	polytetrafluoroethylene
RP	recommended practice
Tg	glass transition temperature
VME	Von Mises’ equivalent stress

3.3 Definitions

3.3.1
corrosion barrier ring
Polymeric ring inserted between adjacent lengths of liner in a tubing string to provide continuity of corrosion protection.

3.3.2
flare or end cap
Molded polymeric component used to cap the cut end of the liner.

3.3.3
FRP liner
A thin wall pipe manufactured from fiber reinforced polymer (FRP) which is inserted within carbon steel tubing to provide corrosion protection.

3.3.4
grout
Polymer or cement which fills the annulus between the liner and the carbon steel host pipe.

3.4 Unit Conversions

USC and equivalent SI units are shown in this standard. Nominal sizes will continue to be shown as fractions. For the purposes of this RP, the fractions and their decimal equivalents are equal and interchangeable. Basic conversions are described in Annex A, and these should be supplemented by the standardized conversion and rounding rules in Annex G of API 5CT where required.

4 Product Description and Materials

4.1 General Product Description

Composite lined carbon steel tubing consists of a thin wall, FRP liner inserted into steel tubing. Typically, the liner is manufactured by filament winding. The annulus between the pipe and tubing is filled with cement or polymer grout, to transfer internal pressure loads to the steel tubing. The ends of the liner may be protected from mechanical damage by an FRP end cap or "flare," which may protrude slightly into the bore of the tubular. These FRP flares, which are bonded in place, may also seal the cut edges of the liner. Continuity of the corrosion barrier (CB) across the coupling, between two adjacent flares, is usually provided by a polymeric CB ring. The amount of compression applied to the barrier ring is controlled by the distance between the pin ends during make-up. Other forms of connection protection device are acceptable.

The carbon steel tubing shall have the required resistance to sulfide stress cracking as defined by NACE MR0175/ ISO 15156 Parts 1, 2, & 3, based on the bore fluid composition. Both API and proprietary connections may be used with composite lining systems.

4.2 Materials

The liners are typically manufactured from an epoxy resin, using an aromatic amine hardener, and reinforced with glass fibers. Other polymers and fibers are permissible to meet particular corrosion or high temperature requirements. Liners shall be manufactured according to the manufacturer's written procedures.

The flares are typically molded from a short-fiber reinforced polymer material, and shall be manufactured according to the manufacturer's written procedures. A suitable adhesive shall be used for bonding the flares to the liners.

The grout is typically a cement system with additives to provide the required flow viscosity, or a thermoset polymer of suitable viscosity.

The CB ring is typically made from a polymer material, usually an elastomer or fiber filled PTFE.

4.3 Functional Requirements

The primary function of the lined tubing system is to protect the carbon steel base pipe from the corrosive effects of the bore fluids.

Factors which may affect the ability of the liner to perform its primary function include:

— Degradation of the FRP liner due to chemical attack.

— Failure, or absence, of the CB ring.

— Mechanical damage by downhole tools, e.g. impact and abrasion.

— Failure of, or damage to, the liner or other components caused by combined load effects, such as combination of tension/compression/bending, pressure and temperature cycling, and connection over-torquing.

5 Qualification Program

The capability of a composite lined product shall be proven by the combination of materials tests and system tests, described in the following sections. Successful completion of these tests has been judged by the industry to provide a robust technical justification for the application of such products.

5.1 Materials Testing

The capability of the materials used in liners, flares, and CB rings shall be demonstrated by the successful completion of the tests described in this section.

5.1.1 Material Capability in Produced or Injected Fluids

All polymeric materials can be subject to physical and chemical degradation when immersed in water, hydrocarbons, and other fluids. Consequently, chemical compatibility with produced and injected fluids, as well as production chemicals (see 5.1.3), must be characterized.

Evaluation of degradation can be made using a number of methods, including:

a) *Monitoring of weight change and swelling*—Weight and volume changes can be used to determine trends and are useful as a source of corroborative information.

b) *Visual observation*—In many cases, change in color and surface finish may only indicate superficial change in properties. However, the formation of blisters and surface damage (delamination and spalling) that result in resin loss and exposure of bare fibers represent unacceptable damage.

c) *Monitoring changes in mechanical properties*—Various mechanical tests are possible, including Barcol hardness, axial and hoop flexure, and tensile ring pull.

d) *Monitoring changes in glass transition temperature, Tg*—Tg measurements can be difficult with high temperature resins (because of the difficulty identifying a true Tg) and with exposed samples (heat drives off absorbed fluids). However, the reduction in Tg of a specimen that has been tested and subsequently dried out may be indicative of degradation. Heat deflection temperature may be a more suitable measure than Tg for some types of resin.

e) *Chemical analysis*—Standard chemical analysis techniques, such as infra-red analysis and mass spectrometry, may be employed in more detailed investigations of chemical degradation mechanisms.

For composite liners, the evaluation of changes in mechanical properties has been found to be a useful method in determining the long term limitations. While a change in mechanical properties may not prevent a liner from performing its intended function, the effect of lower mechanical properties must be evaluated within the lined tubular system.

Accelerated testing at a minimum of three test temperatures, above the likely service temperature, may be used to determine the temperature capability of the liner materials in water, hydrocarbon gas and crude oil service. ISO 2578 provides the principles and procedures for evaluating the thermal endurance properties of plastics, exposed to elevated temperature for long periods. The Arrhenius approach described in this standard may be used to extrapolate the accelerated data to typical service temperature, demonstrating a steady and predictable loss of properties with time at temperature. All mechanical test specimens shall be cut from a production component and for each individual test an average of at least three measurements shall be used. All test samples shall be pre-conditioned in water for at least two weeks before elevated temperature testing. Material within 2 in. (25 mm) of a cut edge of a liner shall not be used in property determination. To date, most success with applying this method to liners has come by using a 3 point bend test in general accordance with ISO 178. An end of life criterion must be selected to allow service life assessment, e.g. stress at break of 14,500 psi (100 MPa) for a glass reinforced epoxy liner, at a particular temperature. Service life assessment in any given application shall take account of prevailing downhole conditions over the life of the well. Other methods of life assessment are permissible subject to agreement between manufacturer and purchaser.

For flares and CB rings, similar tests may be appropriate. In certain instances, documented industry experience may be sufficient to verify the performance of a material, e.g. the chemical resistance of PTFE-based materials.

5.1.2 Effect of Rapid Gas Decompression

Damage may be caused by rapid decompression, particularly in gas applications. The manufacturer shall demonstrate that the materials being used are not damaged in this way. This can be done as part of decompression tests on lined test spools, described in 5.2.2. Alternatively, materials samples should be exposed to a representative gas at the required pressure and temperature for a period up to 10 days, followed by complete decompression at a rate of 100 psi/min (0.011 MPa/s) or more. Internal damage to the material and fracture at the surface shall be considered unacceptable.

5.1.3 Capability in Production Chemicals

Materials are potentially subject to exposure in a wide variety of production chemical treatments. Strong, concentrated solvents, acids and alkalis are known to be potentially damaging.

The manufacturer shall demonstrate the chemical capability of the materials, taking account of typical concentrations, exposure durations, exposure frequencies, and treatment temperature. This data may take the form of mechanical property evaluation, similar to that described in 5.1.1, but over shorter time periods at realistic service temperatures.

5.1.4 Additional Materials Tests

Other tests may be run on materials. In particular the internal surface roughness of the liner should be characterized.

Propensity for wax and scale deposition and ease of their removal can be demonstrated in laboratory tests. When compared to steel in many applications, FRP liners have proven less susceptible to wax and scale deposition. In addition, any deposits which do form are generally much easier to remove from FRP.

Erosion, abrasion and impact tests may also be run, although these tests are typically only comparative in nature and may not demonstrate fitness-for-purpose. Low levels (1 lb/1,000 bbl or < 50 ppm) of sand at up to 33 ft/s (10 m/s) have generally not been found to be an issue for composite lined downhole tubing.

Materials tests on grout may be required if the liner system design is such as to expose the grout to flowing fluids.

5.2 Lined Tubing System Tests

Performance tests shall be carried out with lined tubing samples, including connectors. Where connections are modified to accommodate the liner system, tests shall be carried out with the modified connection. Where a liner and connection system is designed for use without modification, one representative connection shall be selected for test.

5.2.1 Corrosion

The ability of the liner to prevent carbon steel corrosion is well proven and field demonstrated. The manufacturer shall be responsible for the CB integrity of the coupling/connection, and shall be able to demonstrate this integrity for their particular designs of liner and connection geometry. Typically this will be through a combination of static pressure tests at elevated temperature, rocker arm tests, and/or flow loop tests of lined and coupled samples in fluids representative of corrosive downhole environments.

5.2.2 Rapid Decompression

The manufacturer shall demonstrate the resistance of a liner design to external collapse due to build up of pressure behind the liner. Since the liner is a thin wall cylinder, the collapse resistance of a typical composite liner is relatively low compared to the potential well operating pressures. The liner system design must account for the potentially high pressures that could be exerted on the outside of the liner.

For applications involving highly compressible fluids, the manufacturer shall demonstrate that the liner system design will withstand rapid depressurization of the bore, typically at 100 psi/min (0.011 MPa/s) or more, without damage to the liner. This shall be achieved by a full bore depressurization of a sample where the annulus pressure is in equilibrium with the bore pressure. Test samples should typically consist of two separate lengths of threaded tubing/casing, each of a 40 in. (1 m) length minimum, joined together to create a minimum 80 in. (2 m) length test sample. This should be capped at each end with threaded end caps. Pipe diameter, wall thickness, steel grade, thread type and CB system should be representative of the application.

It is the responsibility of the purchaser to ensure that their gas well systems can operate within any decompression limitations identified by the manufacturer.

5.2.3 Make-and-Break Connection Tests

Multiple (typically 5) make-and-break tests shall be carried out according to the connection manufacturer's procedures. Actual torque values should be available for review by the purchaser. There should be no galling at any time, and no significant changes in make up properties from the standard product. There should be no damage of any sort to liners, flares, or barrier rings.

5.2.4 Combined Load Testing

The manufacturer shall demonstrate that the lined system has suitable structural integrity for the mechanical, pressure, and thermal loads to be seen during installation and use in any given service.

This will typically be achieved through combined loading testing according to ISO 13679, as deemed appropriate by the purchaser. The liner system shall not detract from connection performance. The liner system and the connection shall not fail in pressure containment nor change the make up characteristics of the connection. Holiday testing should detect no defects either before or after testing.

The load sequence shall reflect the ISO 13679 requirements of determining or validating a product/connection performance envelope in combined load environment, covering all relevant quadrants of the pipe body VME curve. The combined load steps should simulate loading in well conditions, including axial tensile loading without and with internal pressure, full cycle bending (plus/minus) to 10 °/100 ft (10 °/30.5 m), and compressive axial loading. The sequence of loading shall be reversed and shall be repeated to give a minimum of three complete loading cycles.

These tests shall be carried out at the maximum liner temperature capability, with test specimens representative of the standard product manufactured to the manufacturer's specifications.

Fatigue test data shall be required for applications such as top-tensioned risers on spar developments, where the lined tubing sees dynamic service.

5.2.5 Wireline Abrasion and Tool Impact Tests

The manufacturer shall demonstrate the capability of the lined tubing system to withstand downhole wireline abrasion and tool impact. This will typically require full-scale downhole trials, but alternative tests or well documented field history may be acceptable, as agreed between manufacturer and purchaser.

6 Process and Quality Assurance Requirements

Quality control records required by this RP shall be legible, identifiable, retrievable and protected from damage, deterioration, or loss. These records shall be retained by the manufacturer for a minimum of five years following the date of manufacture. All quality control records required by this RP shall be signed and dated, as established by the manufacturer's procedures.

6.1 Materials

All materials used in the production of the liners and flares, and in the lining process shall be fully traceable. This also applies to the materials for the CB rings.

6.2 Manufacturing of Liner, Flares and CB Rings

The liners may be made by filament winding, extrusion, or other suitable method. The flares will typically be molded. The manufacturer's quality plans for liner and flare manufacture shall be reviewed and approved by the purchaser in advance of manufacture. A single length of liner shall be used in each length of steel tubing.

All relevant production information shall be recorded to maintain full traceability of the materials in each individual liner. The batch numbers of resin, fibers, and hardener shall be recorded. The viscosity and mixing tests of resin and hardener shall be documented. The curing temperature and curing time for each liner shall also be recorded. The glass transition temperature of the cured liner shall be determined by Differential Scanning Calorimetry (DSC), in accordance with ISO 11357-2 or Appendix C of API 15HR, at a frequency of 10 % or once per machine per shift. Other methods of measuring Tg may be used as agreed between manufacturer and purchaser. The wall thickness shall be within –0/+10 % of the specified thickness or as otherwise agreed. The liner shall be free from visible cracks, holes, protrusions, foreign inclusions, or other injurious defects, as established by the manufacturer. The liner shall be uniform within the manufacturer's acceptable limits in terms of color, roundness, density, and physical properties.

The molding process conditions for the elastomer CB rings or the PTFE billets used for CB ring manufacture shall be documented. The filler content and the tensile properties of the processed PTFE material shall be determined according to ASTM D 4745. The CB rings shall be molded and /or machined to the exact dimensions required for the specific type of steel connection used.

6.3 Lining Process

The internal surface of the pipe shall be as per the steel manufacturer's supplied finish. 100 % visual inspection of both flares and liners shall be performed prior to installation.

The viscosity of the grout shall be within the specified limits in the manufacturer's quality document. The minimum injection and backfill pressures shall be stated within the quality control plan. All viscosity checks shall be recorded as a part of the quality plan.

Filling the annulus with grout shall be carried out in accordance with the manufacturer's procedures. A measurable amount of grout shall come out of the end opposite to the injection end, to ensure complete filling without pores in the cement layer. A backfill pressure should be applied to minimize the pore sizes. When the evacuation of air during the grout filling process is achieved by means of an inclination of the pipe, the step shall be at least 2 in. (50 mm). The manufacturer shall be able to demonstrate that the lining process is able to reliably fill the annulus with minimum voidage. This will typically be through the cross-sectioning of a lined tubing length to give a visual demonstration of good fill. This only needs to be done once by the manufacturer, and data made available to any purchaser on request. Control of the lining process, as described above, then gives the purchaser the assurance of good fill. Other means of demonstrating annulus fill may be agreed between the manufacturer and purchaser.

Before flare insertion the grout shall be cured sufficiently so that it does not flow when the pumping apparatus is removed. The liner pipe shall be cut flush to the steel pipe, using appropriate tools to provide a clean cut. The flare shall be tested for insertion. The liner and flare bond areas shall be cleaned and prepared for the adhesive application as specified. The adhesive shall then be applied on the bond area and the flare shall be inserted flush with the steel pipe end. The shelf and pot lives of the adhesive shall be checked before usage. After the adhesive has cured, the flare must be sanded flush with the steel pipe such that the flare does not exceed the outer diameter of the steel pipe. Care shall be taken to prevent damage of the seal shoulder of the connector. The flare/liner adhesive shall be checked visually. Voids are unacceptable.

6.4 Inspection by the Purchaser

When an inspector representing the purchaser desires to inspect pipe or witness quality control tests, the Inspector shall be given reasonable notice of the time at which the product will be available for witness or inspection. The Inspector shall have ready access to all parts of the manufacturer's facility during the fabrication cycle. The manufacturer shall afford all reasonable and safe facilities to satisfy the Inspector that the product is being manufactured in accordance with this standard. All inspections should be made at the place of manufacture prior to shipment, unless otherwise specified on the purchase agreement, and shall be conducted so as not to interfere unnecessarily with the operation of the facility. The purchase agreement may require written acceptance from the purchaser's inspectors for each lot prior to shipment.

7 Dimensions and Markings

7.1 Dimensions

The inside diameter, wall thickness, and drift diameter of the liner shall be specified by the manufacturer.

7.2 Marking

Composite lined tubulars, which have been lined in conformance with this RP, shall be marked by the manufacturer with the date of manufacture (month and year) and a unique manufacturer’s lot identification number. Markings shall be readily visible and applied by water resistant paint or ink stencil. Markings shall not overlap and shall be applied in a manner not to damage the pipe or couplings. Markings shall be applied within three feet of the connection. Additional marking as specified by the manufacturer or purchaser are not prohibited, e.g. marking of the word “LINED” on the pipe.

8 Documentation

8.1 Documentation Provided by the Purchaser

The purchaser shall provide the design and operating conditions for the lined tubing, including:

— System design pressure (and pressure range in the case of cyclic service),

— Maximum and minimum design temperature,

— Internal fluids, and

— Design lifetime.

The full information that shall accompany a purchase agreement for composite lined tubing is outlined in Annex B.

8.2 Documentation Provided by the Manufacturer

The manufacturer shall provide the purchaser with a written description of the liner system. As a minimum, this will include:

— Dimensions, including the nominal inside diameter, wall thickness and weight of the liner, and the drift diameter of the lined tubing;

— Description of all materials used;

— Minimum and maximum operating temperatures;

— Limitations with respect to chemical exposure;

A full qualification test report shall be made available to the purchaser on request. The purchaser shall define the data which is to be provided in the Qualification Test Report.

Additionally, the documentation requirements of Sections 6 and 9 shall be fulfilled.

9 Handling, Storage, Transportation and Installation

The manufacturer shall provide running and handling procedures, for review and approval by the purchaser. As a minimum, these should include:

— Requirements for handling, storage and transportation;

— Preparations for running and equipment required;

— Running procedures;

— Break-out procedures.

Thread condition is critical to the sealing effectiveness of any composite lined system. Unless otherwise requested by the purchaser, the manufacturer shall provide pin and box end thread protection to protect the ends of the lined tubular from damage under normal handling and transportation, as well as to prevent damage by ultra-violet radiation and other weather elements. Non-threaded connections may have special end protection requirements, subject to agreement between manufacturer and purchaser.

Field repair kits should be available for rebonding flares to an otherwise intact liner section. Any repairs shall be carried out according to the manufacturer's written procedures.

Particular attention should be taken with the design of interfaces between composite lined tubing and other downhole equipment, such as packers and safety valves. Such interfaces must be designed to accommodate the appropriate CB rings.

Installation procedures shall specifically mention actions required to check that all CB rings are inserted, and inserted correctly.

Annex A
Unit Conversions

USC units are in all cases preferential and shall be the standard in this RP.

Length	**1** inch (in.)	= **25.4** millimeters (mm) exactly
Pressure	**1** pound per square inch (psi)	**= 0.06894757** Bar Note: **1** Bar = **100** kilopascals (kPa)
Strength or Stress	**1** pound per square inch (psi)	= **0.006894757** Megapascals (MPa)
Mass	**1** pound (lb)	= **0.4535924** kilograms (kg)
Temperature	To convert degree Fahrenheit (°F) to degrees Celsius (°C):	°C = **5/9** (°F – **32**)
Impact Energy	**1** foot-pound (ft-lb)	= **1.3558181** Joules (J)
Torque	**1** foot pound (ft-lb)	= **1.3558181** Newtonmeters (Nm)

Annex B
Purchase Agreement Information

The purchaser should provide the following information with all purchase agreements for composite lined tubing.

Basic Design Data	
Steel grade, tubing weight and internal diameter	
Connection type	
Total number of lengths to be lined	
Design life	
Max/min design temperature	
Normal operating temperature	
Max/min design pressure	
Normal and maximum operating pressures	
Normal and maximum flowrates	
Pressure fluctuations (size and frequency)	
Dynamic service/fatigue requirements	
Fluid Service	
Gas/water/oil/multiphase?	
Production/injection?	
Fluid composition	
CO_2/H_2S content	
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