1.2 ENGINEERING GUIDE

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Introduction

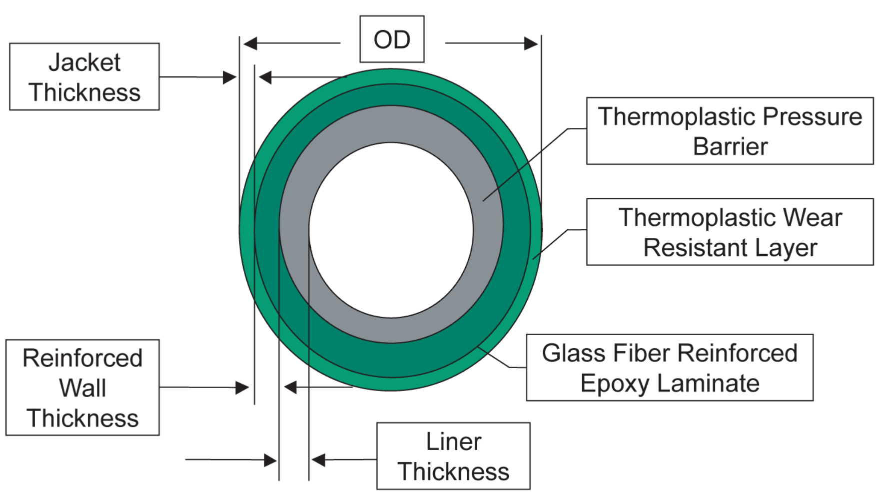
Fiberspar's spoolable fiber-reinforced pipe has been developed to provide the oil and gas industry with a family of products to address the market requirements for a reliable, corrosion-resistant, and cost-effective solution for tubulars used during the production and transportation of oil and gas. Fiberspar LinePipe (FS LP) is a continuously manufactured fiber-reinforced pipe that is designed for production gathering and injection applications. Advantages of FS LP compared to alternative pipeline systems include:

- Rapid and low-cost installation
- Improved corrosion resistance
- Long lengths without joints or connections (up to 27,000 ft, 8 km)
- Improved flow characteristics
- Tolerance to impact damage
- Light weight for improved safety during field installation

Fiberspar LinePipe is designed and manufactured in accordance with the following specifications:

- API 15 HR – "Specification for High Pressure Fiberglass Line Pipe"
- API 15S – "Qualification of Spoolable Reinforced Plastic Line Pipe"
- CSA Z662 Section 13.1 – "Fiberglass Pipeline"
- ASTM D2996 – "Standard Specification for Filament-Wound 'Fiberglass' (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe"
- ASTM D2517 – "Standard Specification for Reinforced Epoxy Resin Gas Pressure Pipe and Fittings"

LinePipe Product Geometry Design Overview



FIBERSPAR LinePipe

Design Overview

The LinePipe consists of an inner thermoplastic pressure barrier layer that is bonded to and reinforced by high-strength glass embedded in an epoxy matrix. This reinforced structure is then jacketed using a thermoplastic material that provides additional protections from impact and abrasion.

Fiberspar LinePipe is available in North America in sizes between 2 1/2" and 6 1/2" with pressure ratings between 300 psi and 2,500 psi (2,068 kPa–17,240 kPa) in continuous lengths of up to 27,000 ft (8.2 km) depending on size and reel capacity. Other sizes and higher-pressure ratings are available by special order.

The selection of the thermoplastic pressure barrier liner is driven by operating temperatures and chemical compatibility with the flow medium. Materials most commonly used are high-density polyethylene (HDPE), which has excellent corrosion resistance up to 140ºF (60ºC) in general water, low vapor pressure (LVP), or gas gathering applications; and high-temperature polyethylene (HTP), which is generally recommended for higher temperature applications. All of these pressure barrier materials are commonly used in the oil and gas industry, with widely published data on performance.

Connectors

Patented Fiberspar LinePipe connectors are a full-strength, field-applied connection system with typical installation times of less than 15 minutes. Drawings of Fiberspar LinePipe compression slip connectors appear in Appendix 9. The service-end connection is used to join the Fiberspar LinePipe to risers, T's or other fittings as required. The standard connector comes pre-welded to a flange, but customers also have the option of a threaded end, bevel end for welding or other custom configuration.

Fiberspar's pipe-to-pipe connector is a full-strength connection used to join two lengths of LinePipe. The pipe-to-pipe design is similar to the service end, except a double seal carrier and two individual slips are used. The tensile and burst properties of the Fiberspar connection exceed the strength of the pipe itself. All qualification and quality tests required by CSA Z662 Section 13.1, API 15 HR, API 15S and ASTM D2996 are conducted using standard Fiberspar LinePipe connectors.

Connectors can be fabricated from numerous alloys depending on application and customer requirements. Commonly used materials for the end connectors include AISI 4140 L80 or A106 Grade B steel. Machining and welding are performed by licensed machine and welding shops with proper QA and QC procedures only. Wetted surfaces are coated depending on customer and application requirements. For example, standard Fiberspar connectors use a Electroless Nickel Coating that is suitable for the majority of chemical and temperature ranges encountered in oil and gas applications. All welding procedures meet or exceed ASME and CSA specifications and include X-ray inspection on welds for every component. The seal rings are chosen based on service requirements, with Viton being the most common. All LinePipe connections are performed in the field by certified technicians who have undergone training and are certified in the proper methods and procedures for installing Fiberspar LinePipe connectors in accord with requirements of API 15 HR, API 15S, ASTM D2517 and CSA Z662 Section 13.1.

Fiberspar Quality System

Overview

Fiberspar has made an extensive commitment to ensure the highest level of quality is employed in the design, manufacture, and installation of every spool of LinePipe. To that end, a four-tier quality-assurance system has been implemented to meet the needs of the oil and gas industry. The Fiberspar quality system meets or exceeds the requirements of API 15 HR, ASTM D2517 and CSA Z662 and is ISO 9001 compliant. An overview of the Fiberspar Quality System is contained in Appendix 1.

Certificate of Conformance

A Certificate of Conformance (COC) is supplied to customers prior to shipment, which summarizes the results from all quality-assurance tests required by Fiberspar's quality system. LinePipe quality control tests meet or exceed the requirements of API 15 HR, API 15S, CSA Z662 Section 13.1 and ASTM D2996 specifications.

Applicable Qualification Standards

API 15 HR — "Specification for High-pressure Fiberglass Line Pipe"

Fiberspar LinePipe is designed and manufactured in accordance with API 15 HR. Quality-control short-term failure pressure tests required by API 15 HR (required every 5,000 ft (1.5 km)) are not ordinarily performed unless otherwise required by customer. Fiberspar's standard LinePipe test interval is at the beginning and end of each continuous length of production, which results ordinarily in testing intervals approximately 10,000 ft (3 km) long.

API 15S — "Qualification of Spoolable Reinforced Plastic Line Pipe"

Fiberspar LinePipe is designed, qualified and manufactured in compliance with API 15S.

CSA Z662 Section 13.1 — "Fiberglass Pipelines"

Fiberspar LinePipe is designed and manufactured in compliance with CSA Z662 Section 13.1.

ASTM D2996 — "Standard Specification for Filament-wound 'Fiberglass' (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe"

Fiberspar LinePipe is designed and manufactured in compliance with ASTM D2996.

ASTM D2517 — "Standard Specification for Reinforced Epoxy Resin Gas Pressure Pipe and Fittings"

Fiberspar LinePipe is able to meet the requirements of ASTM D2517.

Fiberspar LinePipe – Supplemental Qualifications Test

In addition to the qualification tests outlined in API 15 HR, API 15S, CSA Z662 Section 13.1 and ASTM D2996, Fiberspar also conducts supplemental qualification tests to ensure Fiberspar LinePipe is suitable for operating conditions expected in specific commercial applications.

All qualification and quality tests are conducted on specimens that have been pre-conditioned by 10 fully reversed bend cycles to maximum spooling strain per Fiberspar Quality System Work Instruction WI 10.006, “Pre-Conditioning of Test Specimens.”

Fiberspar also conducts quality-control tests over and above the requirements of the listed specifications. Random samples are harvested from within production runs and subjected to destructive testing to verify mechanical and chemical performance. These tests include short-term burst, compression and 1,000-hour elevated temperature survival tests.

Fiberspar has also conducted long-term spooling tests, per Fiberspar WI 10.020, “Long-term Spooling Test,” long-term brine exposure tests on both constituent materials and pipe samples, per Fiberspar WI 10.021, “Long-term Brine Exposure Test,” as well as low-temperature spooling tests to temperatures as low as 55ºF (12.8º C).

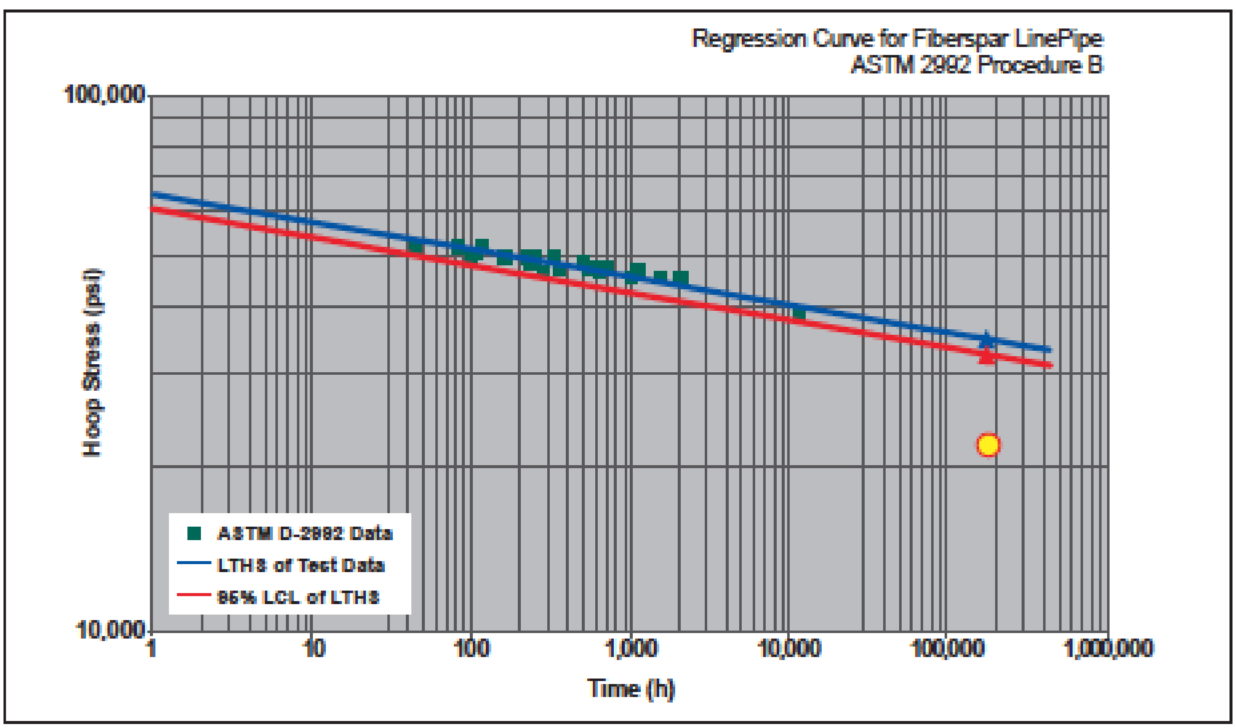
Hydrotests are conducted at 1.5 times operating pressure – per Fiberspar WI 10.005, “Hydrostatic Pressure Proof Test Procedure” – on every foot of Fiberspar LinePipe produced.

Long-term Hydrostatic Strength

ASTM D2992 Testing

The hydrostatic design basis (HDB) of the Fiberspar LinePipe is determined in accordance with ASTM D2992, Procedure B (static), at the maximum rated temperature of the Fiberspar LinePipe. The maximum allowable design pressure for static pressure service for the LinePipe is determined by the formula stipulated in the applicable specification. API 15S specifies that the calculations are based on a 20-year design life, and a minimum 0.67 service factor is applied to the extrapolated data to determine maximum operating hoop stress.

The following is the regression curve with calculated values for Fiberspar LinePipe per ASTM D2992, Procedure B.



Calculations for Fiberspar LinePipe Product Line Per API 15S and CSA Z662 Section 13.1

The regression curve for Fiberspar LinePipe per ASTM D2992, Procedure B, results in a long-term hydrostatic strength (LTHS) of 34,809 psi (24 MPa). The hydrostatic design basis (HDB), which is the 95% lower-confidence limit of the LTHS, is 32,600 psi (22.5 MPa). The hydrostatic design basis (HDS) is therefore 21,842 psi (15 MPa) after applying the 0.67 pressure service factor stipulated by API 15S.

Fiberspar has taken the additional step of using a higher safety factor on the thinner walled, lower pressure LinePipe products. Although this is not required by API or CSA standards, Fiberspar has chosen to incorporate additional structural material in the design of the lower pressure-rated products to mitigate the potentially harmful effects of external abrasion, wear and damage that can occur to pipe during handling, transport and installation operations. Any loss of strength based on external wear would disproportionately affect structural integrity of lower pressure, thin-walled pipe when compared to thicker walled LinePipe products.

For example, the 750 psi (5,171 kPa) Fiberspar LinePipe is designed to have a maximum hoop stress of 14,000 psi (96,527 kPa), compared to 21,824 psi (150,471 kPa) HDS allowable pursuant to API 15S and CSA Z662 for water-based fluid service. This results in a service factor of 0.40 based on the actual regression curve, as opposed to a 0.67 service factor recommended by API 15S.

Fiberspar has utilized this conservative design approach to establish leadership for our products in reliability and robustness for production gathering and injection applications.

Appendix 2 is a data sheet for a representative Fiberspar LinePipe product that is 3-in. ID, 3-1/2 in. nominal diameter with recommended maximum operating pressure by Fiberspar of 1,500 psi (10,342 kPa). Appendix 3 has an example calculation of maximum operating pressure per API 15S in imperial units, and Appendix 4 has a sample calculation per CSA Z662 in metric units. Appendix 5 is a summary of maximum pressure ratings allowable for various fluid services pursuant to CSA Z662 Section 13.1.

Operational and Installation Considerations

Chemical Compatibility and Pressure Barrier Selection

Fiberspar LinePipe is designed to contain a wide range of fluids. Pressure barrier liner selection is based on the specific anticipated service conditions. Appendix 6 contains a list of recommendations for the most commonly encountered fluids for the two standard FS LP pressure barriers, high-density polyethylene (HDPE) and high-temperature polyethylene (HTP). Chemical compatibility information on other pressure barrier materials such as PVDF is available from Fiberspar upon request.

Due to the almost limitless number of combinations, concentrations, temperature and pressure conditions that are possible in the field, Fiberspar Engineering can provide recommendations on a case-by-case basis for specific applications, and can also undertake compatibility testing upon request.

Chemical compatibility of the exterior surface of Fiberspar LinePipe is generally not of concern since the epoxy resin and glass fiber outer surface typically is inert in the environments encountered in most buried applications. In some applications, an external thermoplastic jacket is recommended to provide further protection to the laminate from unusual external conditions, for example if immersed in an aggressive fluid or to provide external collapse resistance from hydrostatic pressure in deep water.

Vibration, Pulsation and Flow Cycling

Applications that use pumps or include pressure cycling may require additional steps to prevent long-term pipe damage or degradation. Systems subject to severe pressure cycling or pulsation may require higher design pipe safety factors per applicable design codes. Applications that will operate on a high-pressure pump, which also cycles several times a day, must be reviewed to determine if any additional safety factors need be applied. All pumps produce pulsation, and pulsation dampeners need to be properly sized and maintained to prevent service failures. Positive displacement pumps are particularly prone to vibration and pulsation problems. Fiberspar Engineering will provide application-specific advice where vibration, pulsation or cycling is a concern.

Pressure Drop Calculations and Abrasive Flow

Fiberspar LinePipe has a smooth internal thermoplastic pressure barrier that improves flow by reducing frictional losses when compared to steel pipe. The smooth interior surface generally does not deteriorate in service, and improved flow properties are maintained over time. Fiberspar recommends that a “C” factor of 150 be used in the Hazen-Williams formula for friction pressure drop calculations. Friction flow factors for other commonly used formulas are contained in Fiberspar LinePipe product data sheets.

Each of the thermoplastic pressure barrier materials used by Fiberspar have good flow abrasion properties and will normally show less abrasive wear than steel pipe under the same abrasive flow conditions. Where highly abrasive flow is expected, tests are recommended to establish wear life.

Pigging and Hot Oiling

Pigs can be run through Fiberspar LinePipe to remove deposits and blockages. However, because the thermoplastic pressure barriers in Fiberspar LinePipe are softer than steel, sharp-edged, scraper-type pigs should be avoided, and soft pigs should be used. Typical low- to medium-density foam pigs or soft urethane cup-type pigs are suitable.

Intermittent hot oiling of Fiberspar LinePipe can be employed up to a maximum hot oil temperature of 20ºC or 40ºF above the maximum-rated operating temperature of the LinePipe. Because of the reduced thermal conductivity of Fiberspar LinePipe as compared to steel, lower hot-oiling temperatures can be employed while maintaining the exit temperature from the line.

Fiberspar engineers can provide information and support for the selection of pig types and sizes to avoid damage to Fiberspar LinePipe, as well as provide technical support regarding temperature profiles for hot oil treatments.

Asphaltines, Paraffins and Hydrates

Formation of asphaltine or paraffin in hydrocarbons is caused by fluid conditions. Build-up of these precipitates inside the tubular occurs when precipitated solids adhere to the pipe wall, and can lead to reduced flow or blockages. Precipitates can adhere to thermoplastics, although this tendency depends on the specific thermoplastic. In all cases the smooth thermoplastic internal pressure barrier material generally aids removal. Fiberspar can provide application-specific technical support based on customer request.

Since hydrate crystals tend to originate in cracks and crevices in the inner pipe surface, the smooth thermoplastic inner surface of Fiberspar LinePipe can have the effect of delaying the onset of hydrate formation, and can be very beneficial in completely preventing any build-up.

UV Resistance and Protection

The outermost layers of Fiberspar LinePipe include a UV-absorbing additive. However, slow degradation of the outer surface of unjacketed pipe will take place when exposed to strong sunlight over time due to the oxidizing effect of UV light on the resins. Testing on fiber-reinforced epoxy pipe conducted over long time periods has demonstrated that structural effects from UV exposure are minimal, as the UV rays are absorbed by the outer layers of the pipe and any damage is limited to the outer 0.010 – 0.020 in. (0.25 – 0.51 mm) of thickness. Any effect on Fiberspar LinePipe from UV rays would be cosmetic, and the pipe can continue to be used to the full rating for the designed 20-year service life.

Static Discharge

Fiberspar LinePipe is an electrical insulator, and in applications that involve transport of non-polar liquids and gases, especially at high velocities, a static charge may be generated on pipe surfaces. If a line requires repair or purging, or if a new connection is needed, grounding and static control procedures should be employed during the intervention. Static electric discharge can ignite a flammable gas or a combustible atmosphere. Where a flammable gas or combustible mixture may be encountered and static electric charges may be present, observe all company (operator, contractor, etc.) procedures for static electricity safety and control, including procedures for discharging static electricity and for personnel protection.

Land Installations

Fiberspar LinePipe can be installed using construction practices commonly employed for stick fiberglass pipe. However, given the flexibility, continuous lengths and axial strength of Fiberspar LinePipe, specialized techniques can be employed that can reduce installation time and costs. Fiberspar’s General Installation Guide, available upon request or for download at www.fiberspar.com, summarizes general good practices, as well as some of the specialized techniques that may be used to install Fiberspar LinePipe.

Pull-through Remediation

Fiberspar LinePipe is ideally suited to repair leaking or failed steel lines by pulling the Fiberspar pipe in a continuous length inside of existing pipelines. This technique is possible because of the continuous, flexible, smooth OD and the high axial strength of the product. Fiberspar has developed installation processes that allow continuous lengths of up to 10,000 ft (3 km) to be used to rehabilitate damaged or failing pipelines. This process provides a full-strength, corrosion-resistant repair, and because of the improved flow characteristics of Fiberspar LinePipe as compared to steel, the reduction in flow area from the pull-through remediation is generally offset by the better flow properties of Fiberspar LinePipe. Fiberspar can design LinePipe specifically to provide the optimum solution where flow rates are critical.

Marine Installations and Weighting

Fiberspar LinePipe is buoyant when not completely full of water and should be weighted in most marine applications. In sub-sea pipeline remediation, it is not necessary to weight LinePipe, as the steel pipe provides sufficient weighting. If LinePipe is pulled into position during the installation process, care must be taken to avoid damaging or snagging the pipe on rocks, sharp surfaces or other objects on the seabed. Fiberspar should be consulted in applications involving weighting of LinePipe.

Fiberspar LinePipe is not recommended in new construction in marine environments where there is significant risk of damage to the LinePipe from construction or fishing activity.

Fiberspar LinePipe can be used in water depths up to 164 ft (50 m). If water depth exceeds 164 ft (50 m), an external thermoplastic jacket can be provided as a special order to ensure collapse resistance from hydrostatic pressure when the pipe is not internally pressurized.

Thermal Movement

As summarized in Section 2, Fiberspar LinePipe is manufactured from thermoplastic pressure barriers and glass fiber-reinforced epoxy resin. The axial thermal expansion coefficient for Fiberspar LinePipe is approximately 12.5×10^{-6} in./in.-°F (2.26×10^{-5} mm/mm-°C), and the hoop-wise thermal expansion coefficient is approximately 7.14×10^{-6} in./in.-°F (1.28×10^{-5} mm/mm-°C).

Because the Fiberspar LinePipe has low axial stiffness compared to steel, forces exerted on end fittings from temperature changes will in almost all cases be negligible. Nonetheless, it is good pipeline design practice to calculate these loads and make sure that sufficient margins are provided to accommodate this loading.

The following formulas can be used to calculate the change in length of Fiberspar LinePipe due to temperature fluctuations, or axial force exerted over a given length.

Given a length of flowline, L, the pipe will extend or grow due to a temperature change of DT:

$\Delta L \quad = \quad L \times a_1 \times DT$

Where:

a_1 = coefficient of thermal expansion in the axial direction

The non-mechanical loads, $P^{non\text{-}mechanical}$, that arise from thermal expansion of Fiberspar LinePipe in the case of fully restrained ends (or segments) can be written as:

$P^{non\text{-}mechanical} = {}'_1{}^{non\text{-}mechanical} \times E_1 \times A4\ a_1 \times \Delta T \times E_1 \times A$

Where E_1 is the axial modulus of elasticity of Fiberspar LinePipe and A is the cross-sectional area of the LinePipe. Thermal expansion curves for any specific Fiberspar product are available upon request, or Fiberspar engineers can supply calculations for specific cases. Appendix 7 contains a typical thermal expansion curve for Fiberspar 3 1/2-in. nominal, 1,500-psi operating pressure LinePipe.

Growth and Shrinkage from Pressure Fluctuation

The mechanical behavior of Fiberspar LinePipe is well characterized. As in the case of thermal expansion, changes in pressure can result in changes in length or axial forces, but again these forces are generally negligible when compared to forces that can be exerted on end components from higher stiffness steel pipeline materials.

Axial force/displacement curves versus pressure for individual Fiberspar LinePipe products are available upon request, and an example of typical properties for 3 1/2-in. nominal, 1,500-psi maximum operating pressure product is contained in Appendix 8.

Fiberspar LinePipe is fabricated with a unique combination of materials and designed with glass fibers oriented such that the Poisson's ratio is greater than 0.5, so the axial hoop strain will induce, through Poisson's effect, an axial contraction that is greater than the axial extension resulting from the pressure-induced axial load. Physically, this means that Fiberspar LinePipe will often contract (or get shorter) when in conventional stick fiberglass or steel line pipe.

Fiberspar Installation Manual

Fiberspar LinePipe should be installed in compliance with the Fiberspar Installation Manual. The Fiberspar Installation Manual is a controlled document and only available to Fiberspar Certified Installers. The Fiberspar General Installation Guide provides general installation advice and guidelines to prospective installers, and is available upon request or for download at www.fiberspar.com.

Fiberspar Connector Installation

Fiberspar connectors must be installed pursuant to API 15S and CSA Z662 standards by Fiberspar-trained and authorized personnel pursuant to Fiberspar's Connector Installation Procedure. Fiberspar is able to train customer personnel or contractors in these procedures for safe installation.

Fire Resistance

The Flammability Classification of Fiberspar products is as follows: "Non-flammable under specified operating conditions. Material will not burn unless exposed to direct flame."

The cured epoxy resin utilized in Fiberspar products is not by nature fire-resistant. Unprotected, it would provide less resistance to fire than would carbon steel. It is not recommended that Fiberspar products be utilized under conditions in which the pipe could be directly exposed to flame for any duration.

Given the implications of the above statements, it is highly recommended that Fiberspar products be completely encapsulated in any situation where exposure to flame is a concern.

Externally Jacketed Pipe

A jacketed version of LinePipe is available and recommended for rocky ground conditions, surface installations or other installations where additional protection is desirable. Fiberspar LinePipe is externally coated with a suitable thickness of a continuous thermoplastic material using a custom extrusion process. This provides additional resistance to damage from point loads or impact. This external jacketing comes standard on most Fiberspar LinePipe products as an added layer of protection. Additional information as well as test reports documenting improved impact and abrasion resistance are available from Fiberspar Engineering.

Plowing with Fiberspar LinePipe

Plowing methodology, which was originally developed for fast and less-disruptive installation of cables and fiber optics, has now been adapted to installation of continuous pipeline systems using advanced and high-capacity plowing equipment. Such plowing equipment can be used with Fiberspar LinePipe and in some situations can be a very high-productivity and economical installation method. Since plowing equipment usually has relatively high deployment costs, viable use of plowing requires a large project, good ground conditions and relatively long, uninterrupted runs with few line crossings. Many Fiberspar installations have been completed successfully using plowing equipment, but not all plowing equipment designs are compatible with Fiberspar LinePipe. More information on plowing techniques and guidelines can be found in the Fiberspar General Installation Guide.

Road and River Crossings

Fiberspar LinePipe is ideally suited for road and river crossings. Techniques are similar to the pull-through techniques described in the Pull-through Remediation Section. While most crossings will involve the use of a casing or conductor pipe, Fiberspar LinePipe has also been successfully used with the slick-bore method, where pipe is inserted directly into a recently drilled horizontal bore without a conductor pipe. For advice or details on crossings and slick bores, contact Fiberspar Engineering.

Application Summary and Customer Reference List — North America

Fiberspar LinePipe has proved to be a cost-effective solution for production, gathering and injection applications, particularly in corrosive applications. Millions of feet have been installed for numerous operators since the company began commercial operations in 1999. Repeat orders from these operators have demonstrated that the product has proved to be an attractive alternative to steel, coated/lined steel and stick fiberglass due to the reduction in joints and couplings, faster installation and competitive costs. A reference list of applications and customers for Fiberspar LinePipe installations in North America is available from Fiberspar upon request.

Appendix 1

Fiberspar Quality System Documentation

QUALITY ASSURANCE MANUAL

QUALITY POLICY STATEMENT

Fiberspar, a leader in the design and manufacture of spoolable fiber-reinforced pipe for the oil and gas industry, is committed to customer satisfaction by achieving excellence in our manufactured products and services that meet and exceed requirements, achieved through employee participation in the continual improvement process and adherence to the improvement of the quality management system.

QUALITY SYSTEM PROCEDURE

WORK INSTRUCTIONS

MATERIAL SPECIFICATIONS

FORMS

EXTERNAL SPECIFICATIONS

CONNECTORS

Appendix 2 – Typical Product Data Sheet

FS LPJ 3 1/2" 1,500 (E)

3 1/2 Inch Nominal, 1,500 Series Fiberspar LinePipe-J w/HDPE Pressure Barrier & HDPE External Wear Layer

Product Data Sheet (Imperial Units) ASTM 2996 Designation: RTRP-11HZ1-4112

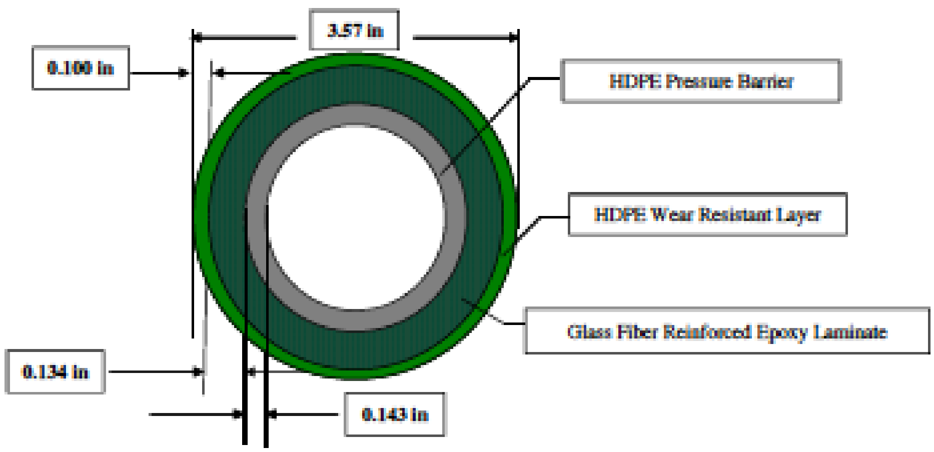
Physical Properties:* Fiberspar s/n: JEEN035026

Geometry		**Tensile Modulus**	
Outside Diameter (in)	3.57	Axial (psi)	8.58E+05
Inside Diameter (in)	2.82	Hoop (psi)	1.11E+06
Inside Flow Area (in²)	6.25	**Poisson's Ratio**	
Total Wall Thickness (in)	0.38	Major	0.49
C/S Area (in²)	3.79	Minor	0.63
Linear Weight		**Thermal Exp. Coeff.**	
Linear Weight - Air (lb/ft)	2.18	Axial (in/in -°F)	1.27E-05
Linear Weight - Water (lb/ft)	0.54	Hoop (in/in -°F)	7.41E-06
Net Density (lb/in³)	0.048	**Thermal Conductivity**	
Flow Coefficients		(BTU/hour/ft²- in/°F)	1.92
Hazen - William's	150	**Resin T_g**	
Darcy-Wiesbach	0.0004	(°C)	125°
Manning	0.009	(°F)	257°

* properties listed are valid for entire temperature range of the product unless otherwise specified

Mechanical Performance:

Maximum Operating Temperature	140 °F		
Minimum Operating Temperature	-29 °F	**78 °F**	**140 °F**
Max. Recommended Operating Pressure (psi)		1,500	1,500
Nominal Ultimate Burst Pressure (psi)		5,700	4,800
Maximum Recommended Tensile Load (lbs)		8,440	7,000
Nominal Ultimate Tensile Load (lbs)		21,100	17,400
Nominal Ultimate Compressive Load (lbs)		-23,400	-19,100
Nominal Ultimate Collapse Pressure (psi)		650	650
Minimum Operating Bend Radius (in)		84	84
Minimum Spooling Diameter (in)		96	96



Appendix 3

API 15S Design Calculation of FS LPJ 3 ½" 1,500 (E) — Imperial Units

Per Equation 1, API 15S 5.1.4 — "The manufacturer shall provide the value of the pressure service factor (PSF). The maximum pressure rating (MPR) is then calculated as the product of LCL and PSF."

MPR = LCL x PSF (1)

Where:

MPR = Fiberspar LinePipe Maximum Pressure Rating per API 15S, psi

LCL = 95% Lower Confidence Limit (LCL) of the Long-term Hydrostatic Strength (LTHS) @ 20 years per ASTM D 2992 Procedure B in psi

PSF = Pressure Safety Factor (0.67 default value as per API 15S)

Per Equation 1 of ASTM D 2992 3.1.8 — "The tensile stress in the wall of the piping product in the circumferential direction due to internal pressure; hoop stress will be calculated by the ISO equation as follows:

$S = P (D - t_r) / 2t_r$ (2)

Where:

P = Internal pressure

S = Hoop stress, psi

D = Average reinforced diameter of the pipe, inches

t_r = minimum reinforced wall thickness of the pipe, inches

For this example: FS LPJ 3 ½" 1,500 (E)

PSF = 0.67

D = 3.334 in.

t_r = 0.134 in.

S = 32,600 psi (HDB from LTHS Testing, ASTM 2992 Procedure B)

Substituting P from Equation 2 for LCL into Equation 1:

$MPR = PSF \times S \times (2t_r / (D - t_r)$ (3)

MPR = 0.67 x 32,600 x (2(0.134 in.) / (3.334 in. - 0.134 in.))

MPR = 1,829 psi

Note: The maximum pressure rating per API 15S for this product is 1,987 psi. To ensure reliable performance in service, Fiberspar rates this product with a higher safety factor than the minimum recommended by API 15S, in this case 22% higher, resulting in a maximum allowable operating pressure of 1,500 psi.

Appendix 4

CSA Z662 Design Calculation of FS LP 3 ½" 1,500 (E) — Metric Units

Per Equation 1, API 15S 5.1.4 (referenced in CSA Z662) — "The manufacturer shall provide the value of the pressure service factor (PSF). The maximum pressure rating (MPR) is then calculated as the product of LCL and PSF."

MPR = LCL x PSF (1)

Where:

MPR = Fiberspar LinePipe Maximum Pressure Rating per API 15S, psi

LCL = 95% Lower Confidence Limit (LCL) of the Long-term Hydrostatic Strength (LTHS) @ 20 years per ASTM D 2992 Procedure B in psi

PSF = Pressure Safety Factor (0.67 default value as per API 15S)

Per Equation 1 of ASTM D 2992 3.1.8 — "The tensile stress in the wall of the piping product in the circumferential direction due to internal pressure; hoop stress will be calculated by the ISO equation as follows:

$S = P(D - t_r) / 2t_r$ (2)

Where:

P = Internal pressure, MPa

S = Hoop stress, MPa

D = Average reinforced diameter of the pipe, mm

t_r = minimum reinforced wall thickness of the pipe, mm

For this example: FS LP 3 ½" 1,500 (E)

PSF = 0.67

D = 87.63 mm

t_r = 4.37 mm

S = 224.8 MPa (HDB from LTHS Testing, ASTM 2992 Procedure B)

Substituting P from Equation 2 for LCL into Equation 1:

$MPR = PSF \times S \times (2t_r / (D - t_r)$ (3)

MPR = 0.67 x 224.8 MPa x (2(4.37 mm) / (87.63 mm - 4.37 mm))

MPR = 15.8 MPa

Per section 13.1.2.8, CSA Z662 an additional service fluid factor (F_{Fluid}) is required to be added to the MRP depending on the type of service the pipe is intended (Water, Multiphase; LVP liquids, Gas). These factors are as follows:

$F_{Water} = 1$

$F_{Multiphase;\ LVP\ liquids} = 0.8$

$F_{Gas} = 0.67$

The design pressure (P_d) is calculated as follows:

$P_d = MPR2F_{Fluid}$

For the FS LP 3 ½” 1,500 (E) example used in Appendix 4:

$P_{d\ Water} = MPR \times F_{Water} = 15.8 \times 1 = 15.8$ MPa

$P_{d\ Multiphase;\ LVP\ Liquids} = MPR \times F_{Multiphase;\ LVP\ liquids} = 15.8 \times 0.8 = 12.6$ MPa

$P_{d\ Gas} = MPR = F_{Water} = 15.8 \times 0.67 = 10.6$ MPa

Note: The maximum pressure rating per CSA Z662 for this product is 15.8 MPa for water service. To ensure reliable performance in service, Fiberspar rates this product with a higher safety factor than the minimum recommended by API 15S, in this case 35% higher, resulting in a maximum allowable operating pressure of 10.3 MPa (1,500 psi).

Appendix 5

Maximum Pressure Ratings per Canadian Standards Association CSA Z662 Pipeline Regulations

				Maximum Design Pressure per CSA Z662-07							
		Fiberspar Max Recommended Design		Oilfield Water		LVP Hydrocarbons		Multiphase Fluids		Gas	
Design ID	Product ID	psi	kPa	psi	kPa	psi	kPa	psi	kPa	psi	kPa
FEBN030026	FS LP 3" 300 (E)	300	2068	300	2068	300	2068	300	2068	300	2068
FEBN040026	FS LP 4" 300 (E)	300	2068	300	2068	300	2068	300	2068	300	2068
FEBN060026	FS LP 6" 300 (E)	300	2068	300	2068	300	2068	300	2068	300	2068
FECN025025	FS LP 2 1/2" 750 (E)	750	5171	1000	6895	750	5171	750	5171	750	5171
FECN035025	FS LP 3 1/2" 750 (E)	750	5171	1000	6895	750	5171	750	5171	750	5171
FECN045025	FS LP 4 1/2" 750 (E)	750	5171	1000	6895	750	5171	750	5171	750	5171
FECN060025	FS LP 6" 750 (E)	750	5171	1000	6895	750	5171	750	5171	750	5171
LEEN025026	FS LP 2 1/2" 1500 (E)	1500	10342	1500	10342	1500	10342	1500	10342	1440	9929
LEEN035026	FS LP 3 1/2" 1500 (E)	1500	10342	1500	10342	1500	10342	1500	10342	1440	9929
LEEN045026	FS LP 4 1/2" 1500 (E)	1500	10342	1500	10342	1500	10342	1500	10342	1440	9929
JEEN060026	FS LPJ 6" 1500 (E)	1500	10342	1500	10342	1500	10342	1500	10342	1200	8274
JEFN045026	FS LPJ 4 1/2" 2250 (E)	2250	15513	2250	15513	2250	15513	2250	15513	1900	13100
JEGN025025	FS LPJ 2 1/2" 2500 (E)	2500	17237	2500	17237	2400	16548	2400	16548	2000	13790
LEGN035025	FS LP 3 1/2" 2500 (E)	2500	17237	2500	17237	2400	16548	2400	16548	2000	13790

				Maximum Design Pressure per CSA Z662-07							
		Fiberspar Max Recommended Design		Oilfield Water		LVP Hydrocarbons		Multiphase Fluids		Gas	
Design ID	Product ID	psi	kPa	psi	kPa	psi	kPa	psi	kPa	psi	kPa
FXBN030026	FS LP 3" 300 (E)	300	2068	300	2068	300	2068	300	2068	300	2068
FXBN040026	FS LP 4" 300 (E)	300	2068	300	2068	300	2068	300	2068	300	2068
FXBN060026	FS LP 6" 300 (E)	300	2068	300	2068	300	2068	300	2068	300	2068
FXCN025025	FS LP 2 1/2" 750 (X)	750	5171	1000	6895	750	5171	750	5171	750	5171
FXCN035025	FS LP 3 1/2" 750 (X)	750	5171	1000	6895	750	5171	750	5171	750	5171
FXCN045025	FS LP 4 1/2" 750 (X)	750	5171	1000	6895	750	5171	750	5171	750	5171
FXCN060025	FS LP 6" 750 (X)	750	5171	1000	6895	750	5171	750	5171	750	5171
JXEN025026	FS LPJ 2 1/2" 1500 (X)	1500	10342	1500	10342	1440	9929	1440	9929	1200	8274
JXEN035026	FS LPJ 3 1/2" 1500 (X)	1500	10342	1500	10342	1440	9929	1440	9929	1200	8274
JXEN045026	FS LPJ 4 1/2" 1500 (X)	1500	10342	1500	10342	1440	9929	1440	9929	1200	8274
JXEN060026	FS LPJ 6" 1500 (X)	1500	10342	1500	10342	1440	9929	1440	9929	1200	8274

Appendix 6

Chemical Resistance Data for HDPE and HTP Pressure Barriers

Chemical Class		Examples	HDPE	HTP
Acids		Carbonic	R at 140ºF (60ºC)	R at 180ºF (82ºC)
		Acetic Acid <25%	R at 140ºF (60ºC)	R at 140ºF (60ºC)
		Hydrochloric <30%)	R at 140ºF (60ºC)	R at 180ºF (82ºC)
		Hydrochloric (>30%)	R at 140ºF (60ºC)	R at 140ºF (60ºC)
		Sulfuric <70%	R at 140ºF (60ºC)	R at 140ºF (60ºC)
		Sulfuric> 70%	C to N	N
		Hydrogen Sulfide	R at 140ºF (60ºC)	R at 180ºF (82ºC)
		Nitric	See Oxidizing Agents	See Oxidizing Agents
Bases		Sodium Hydroxide	R at 140ºF (60ºC)	R at 140ºF (60ºC)
		Calcium Carbonate	R at 140ºF (60ºC)	R at 180ºF (82ºC)
Salts		Calcium Chloride	R at 140ºF (60ºC)	R at 180ºF (82ºC)
		Seawater	R at 140ºF (60ºC)	R at 180ºF (82ºC)
		Ferrous Chloride	R at 140ºF (60ºC)	R at 140ºF (60ºC)
Hydrocarbons	Aliphatic	C1-C4, Methane-Butane	R at 140ºF (60ºC)	R at 180ºF (82ºC)
		C5-C12	R at 73ºF (23ºC)	R at 73ºF (23ºC)
		C5-C12	C at 140ºF (60ºC)	C at 140ºF (60ºC)
	Aromatic	Benzene (100%)	C at 120ºF (49ºC)	C at 175ºF (79ºC)
	Mixed	Crude Oil (100%)	C at 120ºF (49ºC)	C at 175ºF (79ºC)
Alcohols		Methanol	R at 140ºF (60ºC)	R at 180ºF (82ºC)
		Phenol	R at 140ºF (60ºC)	C at 180ºF (82ºC)
		Ethylene Glycol	R at 140ºF (60ºC)	R at 180ºF (82ºC)
Oxidizing Agents		Nitric Acid	R at 140ºF (60ºC)	R at 73ºF (23ºC)
		Hydrogen Peroxide <50%	R at 140ºF (60ºC)	R at 73ºF (23ºC)
		Hydrogen Peroxide (90%)	R at 73ºF (23ºC)	R at 73ºF (23ºC)
Carboxylic Acids, Esters, Aldehydes and Ketones		Acetone, MEK, Acetaldehyde	C at 140ºF (60ºC)	C at 140ºF (60ºC)
		FAP	C at 120ºF (49ºC)	C at 135ºF(57ºC)
Ethers		Diethyl Ether	C at 140ºF (60ºC)	C at 140ºF (60ºC)
Amines		Diethyl Amine	C at 140ºF (60ºC)	C at 140ºF (60ºC)

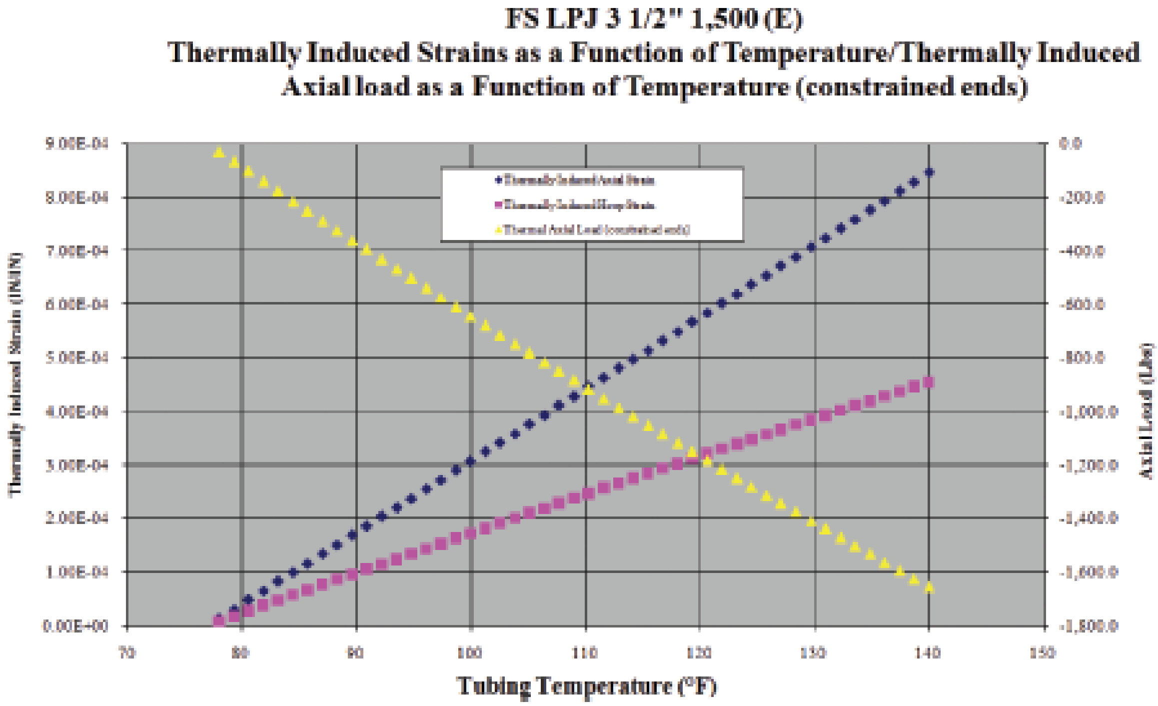
Ratings:

R Recommended for Use
C Conditionally Recommended. Consult Fiberspar Corp.
N Not Recommended

Based on data provided by the materials supplier and recommendations of the Plastics Pipe Institute “Engineering Properties of Polyethylene” and TR-19 “Thermoplastic Piping for the Transport of Chemicals,” and ISO/TR10358:1993

Appendix 7

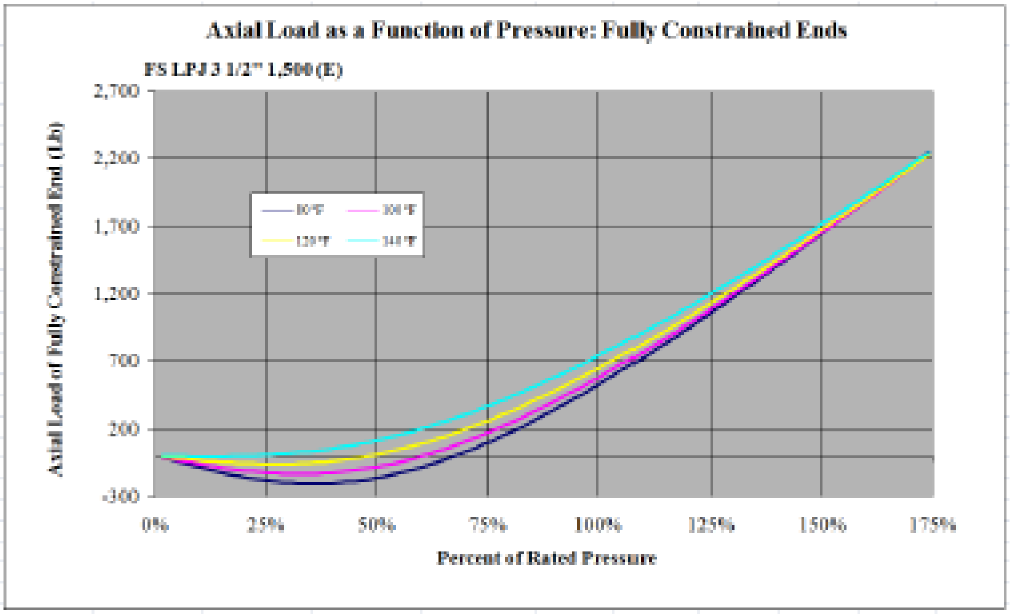
Thermal Expansion Data for FS LPJ 3 ½" 1,500 (E)

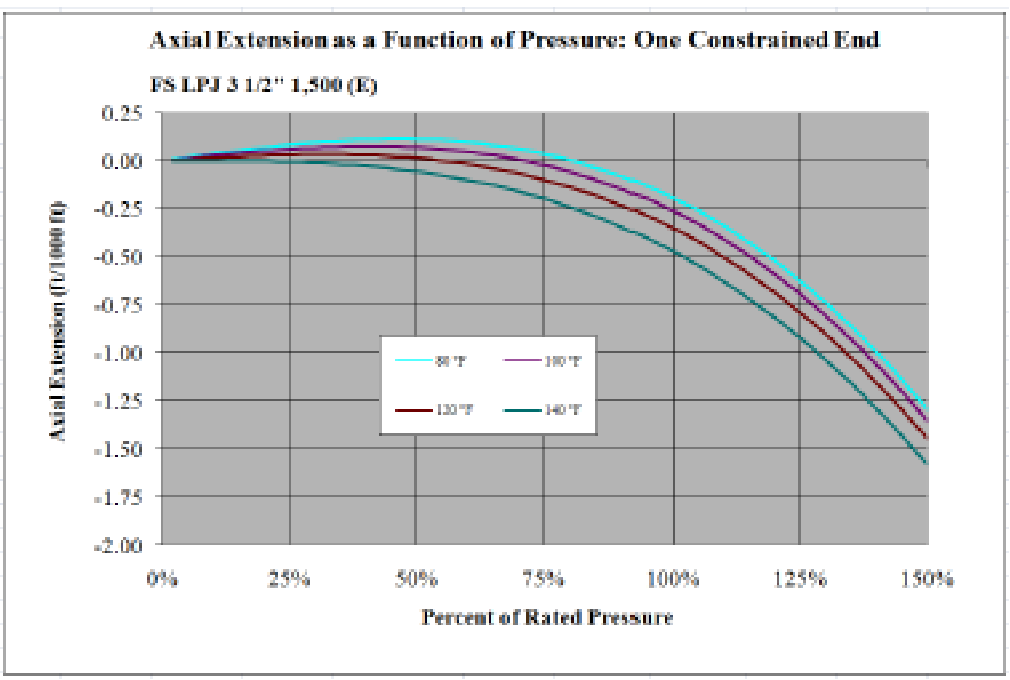


Non-mechanical strains, $e_1^{non\text{-}mechanical}$ and $e_2^{non\text{-}mechanical}$, as a function of temperature for a 3 ½" nominal, 1,500 psi Fiberspar LinePipe. Also, the compressive axial load induced for the same LinePipe with restrained ends as a function of a positive temperature change.

Appendix 8

Pressure Versus Axial Load for FS LP 3 ½” 1,500 (E)

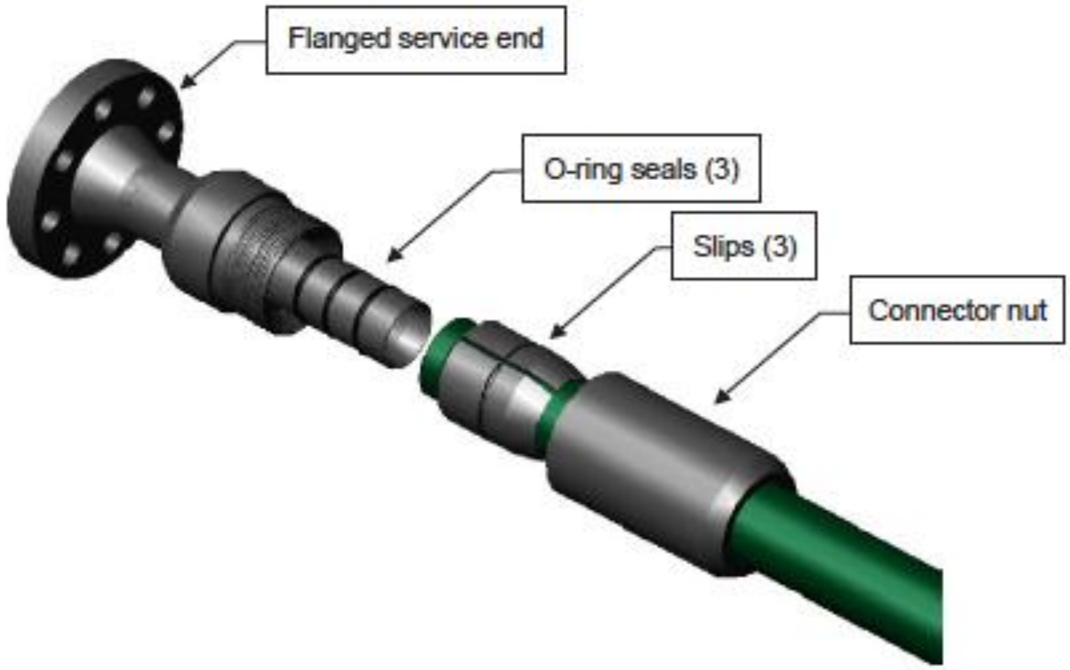




Appendix 9

Fiberspar LinePipe Compression Slip Connector Fittings

Flanged Service End Connector



Pipe to Pipe Connector