HARVEY SVETLIK CONSULTING, LLC
PE Pipe University

1006 Mustang Crossing
Pipe Creek, Texas 78063
817-501-9260

Fused (*) ThermoComposite™ Pipe

ThermoComposite™ Pipe is F-RTP: Fused (*) Reinforced-Thermoplastic-Pipe.

ThermoComposite™ Pipe is typically larger diameter "stick" pipe'. **F-RTP** uses a load-sharing thermoplastic core-pipe, and composite-fiber reinforced thermoplastic sheets, counter-helically wound at specific helix angles in multiple layers over, and fused to, the thermoplastic core-pipe. The end users should understand that the type of reinforcement and design strongly affects the composite pipe mechanical properties. Properties such as tensile strength, impact resistance and cyclic pressure resistance will vary significantly between different pipe products. Therefore, different composite pipe products cannot all be designed and installed in the same manner. Composite pipes are uniquely engineered for general or individual applications. That is a benefit and a burden. Luckily, even with differing composite pipe structures, Global Standards (below) pave the way for engineering and commercial acceptance.

Pertinent Listing Standards:

1.) **ASME Division I / Section VIII:** Minimum Safety Factor of 3.5 on Yield Strength (previously SF=4.0-1) ASME Boiler & Pressure Vessel designs are built with a rupture safety factor of **3.5-to-1**. The Code safety factor was changed in 1999* from **4-to-1** to the current 3.5-to-1.

2.) **ASME BPVC / Section X:** Fiber Reinforced Plastic Pressure Vessels

3.) **ISO TR-13086:** Reinforced Gas Cylinders: Guidance for design of composite cylinders — Part 1: Stress rupture of fibers and burst ratios related to test pressure. **[SF = 3.5: 1]**

4.) **ISO 1119-1 & 2:** Composite Gas cylinders — Design, construction and testing of refillable composite gas cylinders and tube. **[SF = 3.5: 1]**

5.) **API 15S:** Qualification of Spoolable Reinforced Plastic Line Pipe **ThermoComposite™ Pipe is NOT "Spoolable"**

6.) **ASTM D2992:** Obtaining Hydrostatic or Pressure Design Basis for "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe and Fittings. **ThermoComposite™ Pipe is NOT Thermosetting-Resin pipe.**

7.) **ASTM F2686:** Unbonded Glass-Fiber Reinforced Thermoplastic Pipe (6" IPS and smaller). **ThermoComposite™ Pipe is Fused-Fiber, and larger dia. than 6" IPS, in 40-50-ft "sticks".**

8.) **Customer Specification:** **[Customer specified product]**

Note: (*) : **USPTO Product Patent # 10,022,948 B2 & USPTO Process Patent # 8,944,113 B2**

Fused ThermoComposite™ Pipe

For a pipe system or an individual pressure component, an engineer must always verify whether the strength or stability is sufficient for its intended purpose. This verification process requires that the calculated stresses are below the failure stress. Since engineering and manufacturing are not perfect, engineers do not design up to failure but apply safety factors. But what should this safety factor be?

Historically, safety factors used in the piping industry were based on experience. High incidence of failures is a measure of a safety factor that is too low. And so, over the years, safety factors have evolved to what they are today. A different approach to safety factors, rather than trial and error, is making use of the theory of probability. It is possible to determine the chance that the true component stresses are above the true material capacity using the variability of material properties and of geometrical properties of a component. This chance is called the "probability of failure". By defining an acceptable probability of failure, it becomes possible to determine how far the calculated stresses and the documented material capacity have to be separated to arrive at a sufficiently low probability of failure. This distance between the material capacity and the calculated stress is the safety factor.

Per ASME BPVC Section X Class III Composite Pressure Vessels:

For reinforced plastic lined pipe and vessels, the maximum fiber stress is limited up to 28.5% for glass fiber and 44.4% for carbon fiber of the tensile strength of the fiber at design conditions. This corresponds to stress ratios, or **safety factors, of 3.5 for glass fiber** and 2.25 for carbon fiber and is intended to provide reliability with respect to stress rupture in excess of 0.999999 over the life of the vessel.

This minimum 3.5 mechanical strength safety factor additionally corresponds with fatigue endurance of over 250,000 cycles of pressure surge from 10% working pressure rating (WPR) to 100% WPR. The tensile strength of the fiber must be determined through the use of a burst test of a pressure vessel, and not by using quoted values or strand tensile test results, in order to be valid for stress ratio calculations.

Burst Ratio

The ratio of the minimum required burst pressure and the working pressure.

Stress Ratio

The ratio of the minimum strength of the fiber, as determined through burst testing of a pressure cylinder, divided by the stress in the fiber at working pressure. (For a cylinder with a non-load sharing liner, the stress ratio and burst ratio are equal.)

Stress Rupture

Phenomenon by which a reinforcing fiber can fail under an applied tensile load over time, and is dependent on the stress level.

ISO/TR 13086-1:2011(E)

Table 1 — Fibre Stress Ratios to achieve 0,999999 reliability

Fibre Material	Hoop Wrapped, Metal Lined (Type 2)	Fully Wrapped, Metal Lined (Type 3)	Fully Wrapped, Non-metal Lined (Type 4)
Glass	2,65	3,50	3,50
Aramid	2,25	3,00	3,00
Carbon	2,25	2,25	2,25

NOTE 1 Values of 2,35, 2,35, and 2,75 are used on carbon, aramid, and glass respectively for Type 2 cylinders in standards for CNG where settled temperature is 15 °C.

NOTE 2 Values of 2,35, 3,1, and 3,65 are used on carbon, aramid, and glass, respectively, for Types 3 and 4 in some standards for CNG where settled temperature is 15 °C.

NOTE 3 Values of 2,00 are used for carbon for Types 2, 3, and 4 in ISO/TS 15869 for pressures greater than or equal to 350 bar.

Standards that use TABLE 1 stress ratios include: ISO 11439, ECE R-110, ISO/TS 15869, ANSI/CSA NGV2, CSA B-51 Part 2, ASME Section X Class III, KHK Technical Standard #9, ISO13086, & ISO 11119.

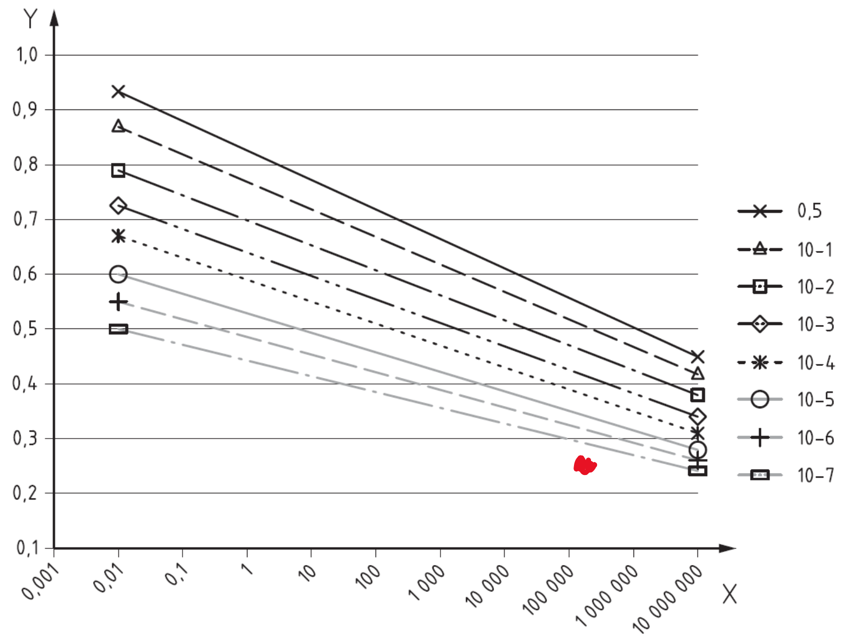
ThermoComposite™ Pipe uses the <u>more conservative</u> Stress Ratio of 4:1 (25% of Maximum Glass Fiber Stress). ThermoComposite™ Pipe meets and slightly exceeds the 3.5 SF design basis of ALL the above standards to provide acceptable 20-year endurance with very high statistical probability of NO rupture from static creep rupture nor dynamic fatigue rupture.

As glass reinforcing fibers were being introduced for use in pressure vessels, stress creep rupture was investigated. A higher stress ratio was required for glass fiber reinforced cylinders in order to provide adequate fatigue reliability and avoid stress rupture. A higher stress ratio for glass fiber solved the problem with stress rupture, and the resultant thicker wall also provided good damage tolerance and durability. Several million glass-fiber reinforced cylinders with the higher stress ratio are in service worldwide and have an excellent safety record.

The reliability for glass, aramid, and carbon fibers, when used at the stress ratios given in Table 1, will all be greater than 0.999999 over the lifetime specified for composite pressure vessels (15-30 years) when held at the rated working pressure (see: Figure 1). At the Stress ratio of 4:1 , the risk of a fiber-glass composite over-wrapped pressure vessel failing due to stress rupture is less than 1 in a million, over its lifetime.

Investigators of stress rupture characteristics of glass fiber include Outwater [1] and Glaser, Moore, and Chiao [2]. The data presented by Outwater was of relatively short duration. The data presented by Glaser, Moore, and Chiao of Lawrence Livermore National Laboratory (LLNL) was gathered over a longer period of time on impregnated strands under constant load. Robinson [3] evaluated the data from USA Lawrence Livermore National Laboratory (LLNL) with results as shown in Figure 1.

Fused ThermoComposite™ Pipe



Key

X time, hours

Y load fraction of median strength

Figure 1 — Glass Composite Strand Stress Rupture Design Chart

Glass-fiber reinforced epoxy pressure vessels are qualified and manufactured in accordance with ASME, ISO, ASTM, and API standards, including API 15S. For spoolable reinforced thermoplastic pipes (RTP)—with the exception of steel reinforced flexible pipe—the **maximum pressure rating** at temperature (MPR) is based on the LTHP testing of pipe samples in accordance with the industry standard test method, ASTM D 2992, which is the same test method used for fiberglass-epoxy stick pipe. Once the testing is completed, the LTHP is calculated in accordance with ASTM D 2992, which involves extrapolation of the test data to determine the LTHP at 20 years (175,200 hours). Then the LTHP is multiplied by a design factor of DF = 0.67, to determine the water rated working pressure at a given temperature.

In some cases, additional pipe qualification may be requested for certain applications …such as: • Effects of permeation on the pipe properties for gas or multiphase services; • Minimum bend radius; • Axial load capability; • External pressure/overburden; • Impact resistance at specified temperatures; • Slow or rapid crack propagation resistance; • High-cyclic pressure services; • Resistance to liner collapse for rapid gas-decompression applications.

ASTM F2992 >> Procedure B:

PROCEDURE B

9. Long-Term Static Hydrostatic Strength

9.1 Select either free-end or restrained-end closures based on the tensile stresses induced by internal pressure and the type of joint in the intended piping system (see 1.4).

9.2 Obtain a minimum of 18 failure points for each selected temperature in accordance with Test Method D 1598 or Test Method F 948 except as follows:

9.2.1 Determine the average outside diameter and the minimum reinforced wall thickness in accordance with Practice D 3567 (Note 8).

9.2.2 The inside environment for the pipe or fitting, test specimens, or both, shall be water. The outside environment shall be air. Other media may be used, but the environment shall be given in the test report. The test liquid shall be maintained within ±5°F (3°C) of the test temperature (Note 9).

9.2.3 The stress or pressure values for test shall be selected to obtain a distribution of failure points as follows:

Hours to Failure	Failure Points
10 to 1 000	at least 4
1 000 to 6 000	at least 3
After 6 000	at least 3
After 10 000	at least 1
Total	at least 18

9.2.4 Maintain the internal test pressure in each specimen within ±1 % of this pressure. Measure the time to failure to within ±2 % or 40 h, whichever is smaller.

9.3 Analyze the test results by using, for each failure point, the logarithm of the stress or pressure in pound-force per square inch or pound-force per square inch gage (kilopascals) and the logarithm of the time-to-failure in hours as described in Annex A1 (Note 8).

9.3.1 A specimen which leaks within one diameter of an end closure may be: (*1*) included as a failure point if it lies above the 95 % lower confidence limit curve; (*2*) repaired and testing resumed provided the new leak is more than one diameter from a test joint, or (*3*) discarded and no failure point recorded.

9.3.2 Those specimens that have not failed after more than 10 000 h may be included as failures in establishing the regression line. Use of such data points may result in a lower or higher static LTHS or static LTHP. In either case, the lower confidence value requirements of 9.4.2 must be satisfied.

NOTE 13—Non-failed specimens may be left under test and the regression line recalculated as failures are obtained.

9.3.3 Determine the final line for extrapolation by the method of least squares using the failure points along with those nonfailure points selected by the method described in 9.3.1 and 9.3.2. Do not use failure points for stresses or pressures that cause failure in less than 0.3 h on the average; determine these points by averaging the times-to-failure of tests made at the same stress or pressure level, that is, a stress within ±200 psi (1380 kPa) or a pressure within ±20 psi (138 kPa). Include in the report all failure points excluded from the calculation by this operation and identify them as being in this category (Note 11).

10. Static Hydrostatic Design Basis

10.1 Calculate the static LTHS at the specified time (100 000 or 438 000 h) as described in Annex A1.

10.2 If $Sxy > 0$ (see A1.4), consider the data unsuitable.

10.3 Calculate r in accordance with A1.4.3. If r is less than the applicable minimum value given in Table A1.1, consider the data unsuitable.

10.4 If required, determine the static HDB category in accordance with Table 1.

11. Static Pressure Design Basis

11.1 Use the procedures in 7.1, 7.2, and 7.3, using pressure in place of stress.

11.2 If required, determine the static PDB category in accordance with Table 2.

ASTM D2992 Testing

The long-term hydrostatic strength (LTHS) of the ThermoComposite™ Pipe is determined in accordance with ASTM D2992, Procedure B (static), at the maximum rated temperature of the ThermoComposite™ Pipe. The maximum allowable design pressure for static pressure service for the ThermoComposite™ Pipe is determined by the formula stipulated in the applicable specification. ASME BPVC Sect X and 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 LTHS data to determine maximum operating hoop stress, and hence, Maximum Rated Pressure (MPR).

The more conservative ThermoComposite™ Pipe's 4:1 stress-ratio (safety factor) supersedes the API 15S and ASTM D2992 composite pipe methodology and conforms with alternative ISO and ASME composite fiber-glass overwrapped pressure vessel design guidance for safe pressure containment and longevity. Based on the typical regression curve, this conservative 4:1 SF design approach results in a service factor lower (better), than the 0.67 service factor recommended by API 15S.

ThermoComposite™ Pipe utilizes this globally accepted, conservative 4:1 stress ratio design approach to establish leadership for its products in reliability and robustness for transport, production, gathering, and injection pipeline applications.

In addition to joint pipe segments using traditional heat butt-fusion procedures (ASME BPVC Div.1 Section IX Part QF Para QF-220: SFPS; ASTM F2620), **ThermoComposite™ Pipe** uses internal (and/or external) custom electro-fusion couplers for joining. The ID couplers join the pipe segments from the inside.

Respectfully submitted,

Harvey Svetlik, P.E.
Texas Registration # 49348

REFERENCES:

[1] OUTWATER, J.O. and SEIBERT, W.J., Strength degradation of filament-wound pressure vessels, *Modern Plastics*, May 1964

[2] GLASER, R.E., MOORE, R.L., and CHIAO, T.T., Life Estimation of an S-Glass/Epoxy Composite Under Sustained Tensile Loading, *Composites Technology Review*, Spring 1983, Vol. 5, No. 1

[3] ROBINSON, E.Y., Design Prediction for Long-Term Stress Rupture Service of Composite Pressure Vessels, Aerospace Report No. ATR-92(2743)-1, The Aerospace Corporation, 1 December 1991

[4] FADDOUL, JAMES, R., Ten Year-Environmental Test of Glass Fibre/Epoxy Pressure Vessels, Lewis Research Center, Cleveland Ohio, NASA TM 87058

[5] CHIAO, T.T., CHIAO, C.C., and SHERRY, R.J., Lifetimes of Fibre Composites Under Sustained Tensile Loading, Preprint UCRL-78367, Lawrence Livermore National Labs, November 17, 1976

[6] BABEL, HANK and GRIMES-LEDESMA, LORIE, Correspondence, Comments on factor of safety for fiber reinforced composite pressure vessels, 17 June 1999

[7] ASME Section X, Fiber-Reinforced Plastic Pressure Vessels, ASME Boiler & Pressure Vessel Code, 2010

[8] NASA/TM—2009-215683: Composite Overwrap Pressure Vessels: Mechanics and Stress Rupture Lifing Philosophy

APPENDIX & NOTES

ISO 11119-2:2020(E)

7.1.3 The cylinders shall be designed for high reliability under sustained load and cyclic loading. Therefore, it is necessary to take account of the properties of the individual composite fibres and to establish their respective minimum fibre stress ratios.

The fibre stress ratio is defined as the fibre stress at calculated design minimum burst pressure divided by the fibre stress at 2/3 test pressure.

The minimum fibre stress ratios shall be as follows:

— for glass: 3,6;

— for aramid: 3,1;

— for carbon: 2,4.

ISO/TR 13086-1:2011(E)

Table 1 — Fibre Stress Ratios to achieve 0,999999 reliability

Fibre Material	Hoop Wrapped, Metal Lined (Type 2)	Fully Wrapped, Metal Lined (Type 3)	Fully Wrapped, Non-metal Lined (Type 4)
Glass	2,65	3,50	3,50
Aramid	2,25	3,00	3,00
Carbon	2,25	2,25	2,25

NOTE 1 Values of 2,35, 2,35, and 2,75 are used on carbon, aramid, and glass respectively for Type 2 cylinders in standards for CNG where settled temperature is 15 °C.

NOTE 2 Values of 2,35, 3,1, and 3,65 are used on carbon, aramid, and glass, respectively, for Types 3 and 4 in some standards for CNG where settled temperature is 15 °C.

NOTE 3 Values of 2,00 are used for carbon for Types 2, 3, and 4 in ISO/TS 15869 for pressures greater than or equal to 350 bar.

ASME BPVC Section X

A load-sharing liner typically is taken past its yield point in an autofrettage pressure cycle, leaving it in a state of compression at zero pressure. This reduces the mean stress in the liner during pressure cycles, increasing the cyclic fatigue life of the metallic liner. Reinforcing fibers operate elastically. Minimum material conditions and geometric irregularities such as out-of-roundness, weld peaking, and weld mismatch must be addressed. One of the key aspects of the analysis is to confirm that the design does not place the fibers above limits that could result in stress rupture of the fibers. The maximum fiber stress is limited to 28.5% for glass fiber and 44.4% for carbon fiber of the tensile strength of the fiber at design conditions. This corresponds to stress ratios, or safety factors, of 3.5 for glass fiber and 2.25 for carbon fiber and is intended to provide reliability with respect to stress rupture in excess of 0.999999 over the life of the vessel.

Burst Test. The vessel is tested hydraulically, to destruction, by pressurizing at a rate of no more than 5 bar/s (70 psi/sec). Three units must be tested during qualification testing. The burst pressure must be at least 3.5 times design pressure for a glass fiber reinforced vessel, and at least 2.25 times design pressure for a carbon fiber reinforced vessel. The pressurization rate is limited to ensure that the pressure is not “spiked”, and that the vessel actually sees the pressure as measured. This test confirms the basic strength of the vessel, and that the requirements for stress level will be met at the design pressure, to assure that the vessel not rupture during its design life.

ADVISORY STATEMENT:

The design of the F-RTP **ThermoComposite™ Pipe** is straightforward. An essential element to this system is the joining method. Butt-Heat-Fusion is well known and has been industrially accepted for over 50 years. However, **ThermoComposite™ Pipe** operating pressures are higher than standard unreinforced thermoplastic (polyethylene) pipe. Depending upon the reinforcement winding angle, number of layers, etc., the fusion joint may be subjected to lower or higher axial stresses. Smaller diameter F-RTP ThermoComposite™ Pipe has been tested for static burst and fatigue; and has been field installed with current success. Further study is indicated and warranted to validate and verify the F-RTP fusion joint performance in pipe diameters larger than 18-inch diameter for specified operating pressures and temperatures.

Relevant ISO Standards:

- **ISO 21307** Plastic Pipe and Fittings – Butt Fusion Procedures for Polyethylene (PE) Pipe and Fittings
- **ISO/TR 11647:1996** Fusion compatibility of polyethylene (PE) pipes and fittings
- **ISO 9356:1989** Polyolefin pipe assemblies with or without jointed fittings; resistance to internal pressure; test method
- **ISO 4427-2:2019** Plastics piping systems for water supply, and for drainage and sewerage under pressure — Polyethylene (PE) — Part 2: Pipes
- **ISO 3458:1976** Assembled joints between fittings and polyethylene (PE) pressure pipes; Test of leakproofness under internal pressure
- **ISO 3459:1976** Polyethylene (PE) pressure pipes; Joints assembled with mechanical fittings; Internal under-pressure test method and requirement
- **ISO 3501:1976** Assembled joints between fittings and polyethylene (PE) pressure pipes; Test of resistance to pull out
- **ISO 3503:1976** Assembled joints between fittings and polyethylene (PE) pressure pipes; Test of leakproofness under internal pressure when subjected to bending
- **ISO 7268:1983** Pipe components; Definition of nominal pressure
- **ISO 9356:1989** Polyolefin pipe assemblies with or without jointed fittings; resistance to internal pressure; test method
- **ISO 11420:1996** Method for the assessment of the degree of carbon dispersion polyolefin pipe, fittings, and compounds
- **ISO 12162:1995** Thermoplastics materials for pipes and fittings for pressure applications - Classification and designation - Overall service (design) coefficient
- **ISO 13761:1996** Plastics pipes and fittings - Pressure reduction factors for polyethylene pipeline systems for use at temperatures above 20
- **ISO 9625:1993** Mechanical joint fittings for use with polyethylene pressure pipes for irrigation purpose
- **ISO 6964:1986** Polyolefin pipes and fittings; Determination of carbon black content by calcination and pyrolysis; Test method and basic specification
- **ISO 7278-2:1988** Liquid hydrocarbons; dynamic measurement; proving systems for volumetric meters; part 2: pipe provers
- **ISO 7370:1982** Glass fiber reinforced thermosetting plastics (GRP) pipes and fittings; Nominal diameters, specified diameters and standard lengths
- **ISO 8361-1:1991** Thermoplastics pipes and fittings; water absorption; part 1: general test method
- **ISO 8572:1991** Pipes and fittings made of glass-reinforced thermosetting plastics (GRP); definitions of terms relating to pressure, including relationships between them, and terms for installation and jointing
- **ISO 9080:2003** Plastics piping and ducting systems - Determination of the long-term hydrostatic strength of thermoplastics materials in pipe form by extrapolation
- **ISO/TR 10358:1993** Plastics pipes and fittings; combined chemical-resistance classification table
- **ISO 10928:1997** Plastics piping systems - Glass-reinforced thermosetting plastics (GRP) pipes and fittings - Methods for regression analysis and their use