FIBERGLASS REINFORCED PLASTIC (FRP) PIPING SYSTEMS

DESIGNING PROCESS / FACILITIES PIPING SYSTEMS WITH FRP

A COMPARISON TO TRADITIONAL METALLIC MATERIALS

Enclosed on the following pages is one in a series of papers written by the Engineering Department of Specialty Plastics, Inc. on fiberglass reinforced plastic (FRP) piping systems. This paper, on designing process and facilities piping systems with FRP, is one in a line of papers written on the basic principles involved in the selection, specification, and design of the components involved in fiberglass piping systems.

Specialty Plastics, Inc., as a designer, manufacturer, and installer of fiberglass pipe systems with two decades experience in the advanced composites industry, provides this paper as a service to its customers involved in the design and selection of fiberglass reinforced plastic piping systems.

The intention of this paper is to present common design principles encountered when engineering a fiberglass piping system. The approach, however, is slightly different, in that the design principles are presented by comparing them to traditional metallic materials. By doing so, the designer who is familiar with these metallic materials can hopefully better understand the unique design considerations of fiberglass piping.

The guidelines drawn in the report are based on the history and experience of Specialty Plastics in the fiberglass composite piping industry. These guidelines, however, are intended to be just that - guidelines. Each application of an FRP piping system is unique and must be treated as such. Furthermore, because of certain intangibles involved with FRP piping systems, a "pre-engineered" system is not recommended. A detailed design of each pipe system is necessary to achieve the full potential of the FRP piping system. By doing so, the customer is ensured of a "custom-designed," "custom-manufactured," and "custom-installed" system to his specifications and needs.

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1 Introduction:

One of the obstacles that FRP (fiberglass reinforced plastic) sometimes has to overcome is proper design of the materials. FRP has unique properties that, if disregarded, can lead to failure during operation. However, when these same unique properties are taken advantage of, they can provide the user with a system superior to traditional metallic materials. This paper discusses some of the basic principles in designing process and facilities piping systems with FRP. Since many users are more familiar with traditional metallic materials, this papers presents those basic principles by comparing the performance of FRP to carbon steels, stainless steels, titanium, and copper-nickel piping.

2 A Comparison of the Materials

2.1 General

There are many general differences between FRP and traditional metallic materials that have been established for many decades. While carbon steels, stainless steels, and copper-nickel are metals, isotropic, and homogenous, FRP is a composite, orthotropic, and heterogenous.

Typical structural materials are normally divided into four basic categories: metals, polymers, ceramics, and composites. A composite is basically a combination of two or more other structural materials. FRP is a composite of a polymer (the resin) and a ceramic (the glass fibers). When we define composites in this manner, we are normally talking about composites formed on the macroscopic level. If we looked at it from the microscopic perspective, we would have to consider most materials to be composites.

By forming a composite such as FRP, an engineer can take advantage of the desirable properties of both constituent materials. In FRP, the glass fibers provide the strength and stiffness while the resin matrix acts as a binder providing impact resistance, compressive strength, and corrosion resistance.

One property of FRP that results from it being a composite is it is non-isotropic whereas traditional metallic materials such as carbon steel are isotropic. When we say isotropic, we mean that the mechanical properties, such as strength and modulus, are the same regardless of direction. In a non-isotropic material, the properties associated with an axis passing through the material will depend on the direction it passes through the material.

Thus, when you look up the mechanical properties of an FRP material, you will often find not one modulus value, but several modulus values, including axial tensile modulus, hoop tensile modulus, and axial compressive modulus. It is extremely important when designing with composites such as FRP that the designer understands the non-isotropic properties of the material and takes this into account in the design process. Treating FRP as an isotropic material would be a poor assumption to make as a design engineer.

A second property that results by forming a composite such as FRP is that the material is now heterogeneous. That is, its composition varies as you move from point to point through the material. Traditional metallic materials, on the other hand, are homogenous. To overcome this, most mechanical properties are averaged. This is achieved by treating the composite as an equivalent homogeneous material and averaging the properties of the constituent materials. In other words, instead of examining the composite on a micromechanical level, we eliminate the inhomogeneity by moving to the macromechanical level. Thus mechanical properties such as axial tensile modulus are sometimes referred to as the "effective" axial tensile modulus.

2.2 Design Temperature

The temperature range of most fiberglass reinforced plastics is much smaller compared to carbon steels, stainless steels, and copper nickel piping. Applications up to 150°F are common with FRP and in some cases can reach as high as 300°F. This, however, is much lower than the temperature encountered with the traditional metallic materials. With these materials, design temperatures can reach 400°F without a considerable degradation in mechanical properties. In the case of stainless steel, the design temperature can reach up to 1100°F and still have an allowable stress above 10,000psi.

Typical Temperature Limits of Process / Facilities Piping

Material	Typical Temperature Limits
FRP	Most common applications are 150EF and below. Some applications up to 250EF with a few special cases up to 300EF. Most resins will begin to degrade above 150EF at a rate of anywhere from 5% to less than 1% per 10EF rise. Some high temperature application resins will maintain 90% of their ambient temperature properties up to 250EF
ASTM A106 Grade B Seamless	No reduction in properties: 400EF 10% reduction in properties: 500EF 20% reduction in properties: 700EF
ASTM A312 TP316L	No reduction in properties: 300EF 10% reduction in properties: 400EF 20% reduction in properties: 600EF
Gr 2 Titanium	No reduction in properties: 200EF 10% reduction in properties: 200EF 20% reduction in properties: Up to 200EF
ASTM B466 90/10 Cu-Ni	No reduction in properties: 100EF 10% reduction in properties: 300EF 20% reduction in properties: Up to 550EF
ASTM B467 70/30 Cu-Ni	No reduction in properties: Up to 100EF 10% reduction in properties: Up to 300EF 20% reduction in properties: Up to 600EF

Source: FRP data is from numerous fiberglass manufacturers. All other data is from ASME B31.3

2.3 Design Stresses

As with design temperature, there is a significant difference between typical allowable stresses in FRP and traditional metallic materials. As the table in this section shows, even for some copper-nickel piping, a typical allowable stress in tension is 9,500 psi at 200EF. With fiberglass, design stresses will vary depending on the type of stress. When designing based on short-term hoop strength against internal pressure, the design stress may vary from 1,500 psi to 3,000 psi. For interlaminar shear strength, the design stress may be as low as 100 psi. For intermittent loads, the design stress may reach as high as 4,000 psi, however, design stresses above 3,000 psi are rare.

Typical Design Stresses

Material	Typical Design Stresses
FRP	Typically 1,000 - 4,000 psi The value varies depending on the type of stress, design life, and other variables
ASTM A106 Grade B Seamless	20,000 psi at 200EF
ASTM A312 TP316L	16,700 psi at 200EF
Gr 2 Titanium	16,700 psi at 200EF
ASTM B466 90/10 Cu-Ni	8,300 psi at 200EF
ASTM B467 70/30 Cu-Ni	9,500 psi at 200EF

Source: FRP data is from numerous fiberglass manufacturers. All other data is from ASME B31.3

2.4 Design Pressure (Typical Sizes are 2" - 12")

Another design variable that differs greatly is the design pressure. Most FRP process piping is used in 150# systems where the pressures are 200psig or lower. While pressures in the thousands of psi can be achieved with FRP, this is usually only seen is specialized applications such as downhole tubing or other applications where special joints can be utilized.

To emphasize the difference in pressures between FRP and traditional metallic materials, most FRP process piping is sold in 50psig increments. That is, you can buy a 12in. FRP product in a 50, 100, or 150psig (and in some cases even higher) pressure class. If you specify a carbon steel material for this same application a designer might use SCH 40 whether the pressure was 50 or 150psig.

This difference raises another point on designing with FRP. While FRP flanges are manufactured to mate with ANSI B16.5 150# (and other classes) flanges, they are not necessarily rated for the pressures and temperatures in the 150# class. For example, a basic carbon steel piping in material group 1.1 would be rated for 285psig at 100EF in the 150# class. As above, an FRP product purchased with 150# flanges would need to have a pressure and temperature rating, typically, anywhere from 50 - 150psig and up to 250EF. Just because you see 150# specified for the flanges in an FRP system does not mean that the system is rated for the 150# pressures and temperatures.

Typical Design Pressures of Process / Facilities Piping

Material	Typical Design Pressures
FRP	Up to 12in. diameter, most chemical plant applications are 150psig or lower. Applications at higher pressures, however, are not uncommon.
ASTM A106 Grade B Seamless	2" SCH 40 (0.154" wall): Up to 1,400 psig 12" SCH 40 (0.406" wall): Up to 900 psig 2" SCH 160 (0.344" wall): Up to 4,600 psig
ASTM A312 TP316L	2" SCH 10S (0.109" wall): Up to 1,600 psig 6" SCH 10S (0.134" wall): Up to 700 psig 2" SCH 40S (0.154" wall): Up to 2,500 psig 6" SCH 40S (0.280" wall): Up to 1,500 psig
Gr 2 Titanium	2" SCH 10 (0.109" wall): Up to 1,500 psig 14" SCH 10 (0.25" wall): Up to 600 psig
ASTM B466 90/10 Cu-Ni	2" Wgt Class 200 (0.083" wall): Up to 600 psig 12" Wgt Class 200 (0.25" wall): Up to 300 psig
ASTM B467 70/30 Cu-Ni	2" Wgt Class 200 (0.083" wall): Up to 500 psig 12" Wgt Class 200 (0.25" wall): Up to 300 psig

Source: Data is from various users of these products.
Based on ASME B31.3, $P = 2SE(t-A)/(D-2y(t-A))$, $y = 0.4$, $E = 1.0$, $A = 0.0$, and $S =$ 20,000psi at ambient for carbon steel, 16,700psi at ambient for stainless, 16,700psi at ambient for titanium, 8,700psi at ambient for 90/10 Cu-Ni, and 10,000psi at ambient for 70/30 Cu-Ni.

3 Design Examples

3.1 Density

It is well known that fiberglass reinforced plastics are much lighter than carbon steels and other metallic piping materials. Densities of these materials are provided in the table below.

Typical Densities

Material	Density
FRP	0.06 - 0.065 lb/cu in.
Carbon Steels	0.28 - 0.29 lb/cu in.
Stainless Steels	0.29 lb/cu in.
Gr 2 Titanium	0.163 lb/cu in.
90/10 Cu-Ni	0.32 lb/cu in.
70/30 Cu-Ni	0.32 lb/cu in.

Source: FRP data is from numerous fiberglass manufacturers. All other data is from Nayyar, *Piping Handbook*, 6th Edition

Below are the equations used to calculate pipe weight.

$$\text{Pipe weight per foot} = \frac{p}{4}(OD^2 - ID^2) * r * \frac{12in.}{1ft}$$

OD - Pipe outside diameter, in.
ID - Pipe inside diameter, in.
? - Material density, lb/cu in.

Consider a 4in. fiberglass pipe product with a 0.25in. wall (4.5in. OD, 4.0in. ID) and a 0.065 lb/cu in. density. A 20 foot section of this pipe would weigh 52 lbs. A 4in. SCH 40 carbon steel 20 foot section (4.5in. OD, 4.026in. ID, 0.29 lb/cu in. density) would weigh 221 lbs.

3.2 Thermal Expansion

While it is commonly thought that the thermal expansion of fiberglass is several times higher than carbon steels, it is at most 2.5 times that of carbon steel and at most 1.67 times that of stainless steels. And with some filament wound fiberglass reinforced plastics, the difference is much less. The rate of thermal expansion in FRP products is highly dependent upon the amount of glass in the product and the orientation of the glass. This is because the thermal expansion of the resin is approximately 2.0 - 3.5 x 10^{-5} in./in./EF and the thermal expansion of the glass is only 0.28 x 10^{-5} in./in./EF. In some resin rich hand layup products, a thermal expansion coefficient of 1.5 x 10^{-5} in./in./EF is not uncommon. With most filament wound products, it is closer to 1.0 x 10^{-5} in./in./EF.

Typical Thermal Expansion Coefficients
(valid up to 300EF)

Material	Thermal Expansion Coefficient
FRP	0.9 - 1.5 x 10^{-5} in./in./EF
Carbon Steels	0.6 - 0.65 x 10^{-5} in./in./EF
Austenitic Stainless Steels	0.9 - 0.95 x 10^{-5} in./in./EF
Gr 2 Titanium	0.48 x 10^{-5} in./in./EF
90/10 Cu-Ni	0.9 - 0.95 x 10^{-5} in./in./EF
70/30 Cu-Ni	0.8 - 0.85 x 10^{-5} in./in./EF

Source: Gr 2 Titanium data is from Nayyar, *Piping Handbook*, 6th Edition. 90/10 Cu-Ni source is unknown. All other data is from ASME B31.3.

Refer to the equations below for calculating the thermal expansion per 100 ft of piping.

$$\Delta_{Thermal} = C_t * \Delta T * (100\,ft) * (\frac{12in.}{1ft})$$

? $_{thermal}$ - Thermal expansion, in./100 ft
C_t - Coefficient of thermal expansion, in./in./EF
? T - Temperature change, EF

Consider a 24in. fiberglass piping system operating at 180EF. Ambient temperature is 75EF. What is the thermal expansion per 100 ft of piping?

With a thermal expansion coefficient of 0.00001 in./in./EF, the thermal expansion per 100 ft is 1.26 in./100 ft. The same system in carbon steel, with a thermal expansion coefficient of 0.000006 in./in./EF would expand 0.76 in./100 ft.

3.3 Pressure Expansion

Unlike most metallic systems, it may be necessary to calculate the potential pressure expansion in FRP piping systems. In some cases, the pressure expansion can be equal in magnitude to the thermal expansion. This is mainly due to the low modulus of FRP products.

While the pressure expansion would have to be calculated for each pipe size and wall thickness, in general, FRP products can have a pressure expansion that is 25 times greater than carbon steels and stainless steels and 16 times greater than copper-nickel piping.

Refer to the equation below for calculating the pressure expansion.

$$\Delta_{\text{Pressure}} = \left(\frac{1}{2 * E_t} - \frac{v_{\min}}{E_h}\right) * \left(\frac{P * r}{t}\right) * (100\,ft) * \left(\frac{12 in.}{1\,ft}\right)$$

? $_{pressure}$ - Pressure expansion, in./100 ft
E_t - Axial tensile modulus, psi
E_h - Hoop tensile modulus, psi
v_{min} - Minor poisson's ratio
P - Internal pressure, psig
r - Pipe outside radius, in.
t - Wall thickness, reinforced, in.

To illustrate the magnitude of pressure expansion in FRP products, refer to the table below. The values in the table are termed "pressure expansion factors." To calculate the actual expansion per 100ft of piping, you would need to multiply this value by (P * r / t).

Pressure Expansion Factor

Material	Magnitude of Pressure Expansion	Comparison to Carbon Steel
FRP (1.4 x 10^6, 2.3 x 10^6, 0.5)	2.0 x 10^{-4}	25x greater
Carbon / Stainless Steels (30 x 10^6, 0.3)	0.08 x 10^{-4}	-----
Gr 2 Titanium (15.5 x 10^6, 0.3)	0.15 x 10^{-4}	2x greater
90/10 Cu-Ni (18 x 10^6, 0.3)	0.13 x 10^{-4}	1.6x greater
70/30 Cu-Ni (20 x 10^6, 0.3)	0.12 x 10^{-4}	1.5x greater

Values in parenthesis are axial tensile modulus, hoop tensile modulus (if different from axial), and minor poisson's ratio.

Consider a 12in. fiberglass piping system with a 0.50in. wall thickness (including a 0.02in. liner). It operates at 200psig and 30EF above ambient. Calculate the pressure expansion.

Using the equation above and with E_t = 1,400,00 psi, E_h = 2,200,000 psi, v = 0.35, v_{min} = 0.55, the pressure expansion is 0.34in./100 ft. Compared to a SCH 40 steel system, with $E_t = E_h$ = 30,000,000 psi, v = v_{min} = 0.3, t = 0.375, r = 6.375, the pressure expansion is 0.03in./100 ft.

The thermal expansion of the fiberglass piping, with C_t = 0.00001 in./in./EF is 0.36in./100 ft. Thus, the pressure expansion is almost 50% of the total expansion. The thermal expansion of the carbon steel piping, with C_t = 0.000006 in./in./EF is 0.22in./100 ft. Thus, the pressure expansion is only 12% of the total expansion.

3.4 Modulus of Elasticity

Modulus values of typical FRP products will be 10 - 30 times less than their traditional metallic counterparts. This is typical for FRP products manufactured with E-glass fibers. Composites manufactured with advanced fibers, such as graphite or carbon, would have modulus values higher than those manufactured with E-glass fibers. This is because the stiffness of the carbon and graphite fibers is 3 - 10 times greater than the E-glass fibers.

Typical Modulus Values

Material	Modulus Value (In Tension)
FRP	1 - 3 x 10^6 psi, 70 - 250EF
Carbon Steels	27 - 30 x 10^6 psi, 70 - 200EF
Stainless Steels	26 - 29 x 10^6 psi, 70 - 200EF
Gr 2 Titanium	15 - 16 x 10^6 psi, 70 - 200EF
90/10 Cu-Ni	17 - 18 x 10^6 psi, 70 - 200EF
70/30 Cu-Ni	20 - 22 x 10^6 psi, 70 - 200EF

Source: FRP data is from numerous fiberglass manufacturers. All other data is from ASME B31.3

This lower modulus value can affect many of the design properties. For example, consider the end loads generated in a straight run of piping anchored at both ends. The equations used for calculating this end load are:

$$P = A * E * \Delta$$

$$A = \frac{p}{4} * (OD^2 - ID^2)$$

$$\Delta = C_t * \Delta T$$

P - Anchor load, lbs
A - Cross-sectional area, total, in.^{2}
E - Axial tensile modulus, psi
? - Expansion, in./in.
C_t - Coefficient of thermal expansion, in./in./EF
? T - Temperature change, EF

To illustrate this, consider a 16in. diameter fiberglass product with a 5/16in. wall (16.875in. OD, 16.25in. ID, A = 16.26 in.^{2}) and an axial tensile modulus of 1,400,000 psi. It is designed to operate at 80EF above ambient. Calculate the anchor load.

The expansion at an 80EF temperature change, with C_t = 0.00001in./in./EF would be 0.96in./100ft = 0.0008in./in. The anchor load (for a straight section of pipe anchored at both ends) would be 18,211 lbs.

Consider a stainless steel product in the same size, with a 0.25in. wall thickness (16.00in. OD, 15.50in. ID, A = 12.37 in.^{2}). At the 80EF temperature change, with C_t = 0.000009in./in./EF, the expansion would be 0.86in./100ft = 0.00072in./in. The anchor load, with a modulus of 28,000,000 psi, would be 249,379 lbs.

Another effect is on the support spacing. Below are the equations used for calculating support spacing for a single span beam based on deflection and stress.

$$L_s = (\sqrt[1/4]{\frac{E * I * \Delta}{0.013 * w_o}}) * (\frac{1 ft}{12 in.})$$

$$L_s = \sqrt{\frac{s * I}{\frac{w_o * c}{8} * (\frac{144 in.^2}{1 ft^2})}}$$

L_s - Support spacing, ft (1st equation is based on deflection; 2nd is based on stress)
E - Axial flexural (bending) modulus, psi
I - Moment of inertia, reinforced, in.^{4}
? - Allowable deflection, typically 0.50in.
w_o - Pipe and fluid weight, lb/in.
s - Allowable bending stress, psi
c - Pipe outside radius, in.

Consider a 3in. fiberglass system carrying water. The wall thickness is 0.25in. (0.23in. reinforced). What is the allowable support spacing for single span conditions?

With E = 1,400,000psi, w_o = 0.41 lb/in. (with 1.0 SG fluid), I = 3.17 in.^{4}, and c = 1.75in. (3.50in. OD, 3.00in. ID), the maximum support spacing based on an allowable deflection of 0.50in. is 14.2 ft. If the design is limited to 500psi bending stress, then the maximum support spacing is 10.4 ft.

A SCH 40 carbon steel pipe has E = 30,000,000psi, w_o = 0.90 lb/in. (with 1.0 SG fluid), I = 3.02 in.^{4} and c = 1.75in. (3.50in. OD, 3.068in. ID). Using an allowable stress of 1,500psi, the maximum support spacing is 12.6 ft.

3.5 Thermal Conductivity

While not critical to the pressure integrity or mechanical strength of the system, the low thermal conductivity of FRP products can sometimes be taken advantage of in the design process. As the table in this section illustrates, the thermal conductivity of FRP products is 100 - 300 times less than carbon steels, 70 - 170 times less than 70/30 copper-nickel, and 35 - 90 times less than stainless steels.

Typical Thermal Conductivities

Material	Thermal Conductivity
FRP	0.1 - 0.24 Btu-ft/hr-ft^2-EF
Carbon Steels	25 - 30 Btu-ft/hr-ft^2-EF
Stainless Steels	9 Btu-ft/hr-ft^2-EF
Gr 2 Titanium	9 - 11.5 Btu-ft/hr-ft^2-EF
90/10 Cu-Ni	29 Btu-ft/hr-ft^2-EF
70/30 Cu-Ni	17 Btu-ft/hr-ft^2-EF
Fiberglass / Mineral wool	0.024 - 0.033 Btu-ft/hr-ft^2-EF
Polystyrene foam	0.019 Btu-ft/hr-ft^2-EF

Source: FRP data is from numerous fiberglass manufacturers. 90/10 Cu-Ni source is unknown. All other data is from Nayyar, *Piping Handbook*, 6th Edition

Unfortunately, the thermal conductivity of FRP is not nearly as low as typical insulation materials such as fiberglass, mineral wool, and polystyrene foam. Because of this and because the insulation materials are typically 1 - 2in. thick, the use of FRP over typical traditional metallic materials may not eliminate the need for insulation.

To illustrate the difference between FRP and metallic materials, refer to the following equations for calculating the heat transfer rate in an uninsulated piping system. These equations are based on steady state conditions.

$$\frac{q}{L} = \frac{T_{Fluid} - T_{Ambient}}{\frac{\ln(\frac{r_o}{r_i})}{2 * p * k} + \frac{1}{h_o * A_o}}$$

$$\frac{q}{L} = \frac{T_{Fluid} - T_{PipeOD}}{\frac{\ln(\frac{r_o}{r_i})}{2 * p * k}}$$

$$\frac{q}{L} = \frac{T_{PipeOD} - T_{Ambient}}{\frac{1}{h_o * A_o}}$$

$$A_o = 2 * p * r_o$$

q/L - Heat transfer rate per unit length of pipe, Btu-in/hr-ft^2
T_{fluid} - Fluid temperature, EF
$T_{ambient}$ - Ambient (surroundings) temperature, EF
r_o - Pipe outside radius, in.
r_i - Pipe inside radius, in.
k - Thermal conductivity, Btu-in./hr-ft^2-EF
h_o - Convection coefficient, Btu/hr-ft^2-EF
A_o - Pipe surface area per unit length, in.
T_{PipeOD} - Temperature at outside radius of pipe, EF

Consider a 6in. fiberglass piping system with a 0.375in. wall (6.75in. OD, r_o = 3.375in., r_i = 3.00in., A_o = 21.2 in.) and a 'k' value of 1.3 Btu-in./hr-ft^2-EF. Use h_o = 4.0 Btu/hr-ft^2-EF. What would be the temperature on the outside of the pipe if the fluid temperature is 250EF and the ambient temperature is 75EF?

First, calculate the heat transfer rate per unit length using the first equation. It is 6,676 Btu-in./hr-ft^2. Using the second or third equation, we can now calculate the pipe outside temperature as 153.7EF.

The same calculations for a 6in. SCH40 carbon steel system (6.625 OD, 6.065 ID, r_o = 3.3125, r_i = 3.0325, A_o = 20.81 in.^{2}, k = 27 Btu-in./hr-ft^2-EF) has the heat transfer rate per unit length as 13,962 Btu-in./hr-ft and the pipe outside temperature as 242.7EF.

4 Other Considerations

4.1 Fire Performance

One characteristic not often thought of with FRP is its performance in a fire. Even though FRP is a plastic, certain fire retardant versions of FRP can perform very well in certain fire endurance conditions. One characteristic that contributes to this is the melting point of the materials. While the resin can not perform under the high temperatures of a fire, the melting point of the glass reinforcement is very high and thus it maintains much of its structural integrity during the fire. Furthermore, the glass reinforcement tends to insulate the interior of the product from the extreme temperatures. Because of this, it is not uncommon for a fire retardant FRP product to be able to withstand a hydrocarbon fire at temperatures up to 1800EF for 30 minutes.

Typical Melting Points

Material	Melting Point
FRP Glass Resin	 Above 2900EF Not Applicable
Carbon Steels	2600 - 2800EF
Stainless Steels	2500 - 2600EF
Titanium	3002 - 3038EF
90/10 Cu-Ni	Not Available
70/30 Cu-Ni	2140 - 2260EF

Source: Nayyar, *Piping Handbook*, 6th Edition except for FRP - Glass which is based on $Si0_2$ from *Handbook of Chemistry and Physics*

4.2 Standardization

One characteristic that is often seen as a shortcoming with FRP is its lack of standardization. It is simply not possible to go out and purchase Schedule 40 FRP in the same manner you would traditional metallic materials.

While this may seem to be a disadvantage at first, those who gain more and more experience with composites can begin to see its advantages. The main advantage is the flexibility that the product offers during the design phase. There are dozens and dozens of variables in the manufacturing process that allow the designer and manufacturer to produce a customized product suitable for specific applications. For example, at one basic FRP manufacturing facility, there may be three (3) manufacturing processes, 11 resin systems from three (3) resin families, three (3) catalyst systems, and three (3) types of glass reinforcements. These are all used to produce FRP piping products. Each of these variables would be determined based on 1) the design pressure, 2) the design temperature, 3) the fluid service, 4) the presence of occasional loads (such as wind, seismic), 5) impact requirements, and other design variables.

In addition, there are dozens of additives and manufacturing variables for producing products with 1) UV protection, 2) fire retardancy, 3) gel time retardance / acceleration, 4) conductivity, and 5) abrasion resistance. Because of all of these variables, it becomes very difficult to write a complete specification covering the manufacture and fabrication of FRP piping products. This has in part caused the current state of lack of standardization. Once again, however, as one becomes more and more familiar with the composites industry and sees the advantages of FRP, it becomes apparent that flexibility in design is one of its greatest advantages.

5 Summary of Data

Summary of Data (Table 1)*

Material	Temperature Limit (EF)**	Design Stress (psi)	Design Pressures (psig)***	Density (lb/cu in.)	Thermal Expansion (in./in./EF)
FRP	Up to 250EF	1,000 - 4,000	Up to 150psig	0.06 - 0.065	0.9 - 1.5 x 10^{-5}
ASTM A106 Gr B Seamless	Up to 700EF	20,000 at 200EF	Up to 1400psig (SCH 40)	0.28 - 0.29	0.6 - 0.65 x 10^{-5}
ASTM A312 TP316L	Up to 600EF	16,700 at 200EF	Up to 1600psig (SCH 10S)	0.29	0.9 - 0.95 x 10^{-5}
Gr 2 Titanium	Up to 200EF	16,700 at 200EF	Up to 1500psig (SCH 10)	0.163	0.48 x 10^{-5}
ASTM B466 90/10 Cu-Ni	Up to 550EF	8,300 at 200EF	Up to 600psig (Wgt Class 200)	0.32	0.9 - 0.95 x 10^{-5}
ASTM B467 70/30 Cu-Ni	Up to 600EF	9,500 at 200EF	Up to 500psig (Wgt Class 200)	0.32	0.8 - 0.85 x 10^{-5}

* Refer to the previous sections for notes and information on the data provided in this table.
** The temperature limit is the temperature at which properties are reduced by as much as 20%.
*** Design pressures are typical of piping components 2in. - 12in.

Summary of Data (Table 2)*

Material	Pressure Expansion Factor	Modulus (psi)	Thermal Conductivity (Btu-ft/hr-ft^{2-E}F)	Melting Point (EF)	
FRP	2.0 x 10^{-4}	1 - 3,000,000	0.1 - 0.24	> 2900 (Glass)	
ASTM A106 Gr B Seamless	0.08 x 10^{-4}	27 - 30,000,000	25 - 30	2600 - 2800	
ASTM A312 TP316L	0.08 x 10^{-4}	26 - 29,000,000	9	2500 - 2600	
Gr 2 Titanium	0.15 x 10^{-4}	15 - 16,000,000	9 - 11.5	3002 - 3038	
ASTM B466 90/10 Cu-Ni	0.13 x 10^{-4}	17 - 18,000,000	29	Not Available	
ASTM B467 70/30 Cu-Ni	0.12 x 10^{-4}	20 - 22,000,000	17	2140 - 2260	

* Refer to the previous sections for notes and information on the data provided in this table.