There are 4 approaches to modeling non-metallic piping in AutoPIPE:

1) Using ASME B31.3 and pseudo stress method. Built in FRP manufacturer library AutoFRP.lib can be used with this code which has FRP material database of common FRP manufacturers like Fibercast, Conley, Ameron etc. It is typically based on a tensile stress limit.

2) BS7159 (similar to ISO14692) is more common rigorous method and has built-in BS7159 laminates or can be used with a custom library.

3) Using ASME B31.8, similar to the modeling approach for ASME B31.3 above.

4) Using ISO 14692, an international standard dealing with qualification, manufacturing, design, and installation of GRE / GRP piping systems. This option is only available in AutoPIPE 9.5 and higher.

Notes:

1. Any version of AutoPIPE (Standard, Plus, or Nuclear) can be used to analyze a model with ASME B31.3 or B31.8 piping code. However, AutoPIPE Plus or Nuclear version must be used if analyzing per BS7159 or Iso 14692 piping code. The standard version does not have these piping code options available.

2. AUTOFRP is a built-in FRP material library which can be used with any code but is commonly referred to with ASME B31.3. A material library can be selected from the Tools> Model Options> General dialog screen (additional materials can be added; contact Bentley for more information).

3. SIF and bend flexibilities values should be reviewed and corrected as needed for non-metallic fittings.

4. Spiral wound FRP / GRP typically follows Anisotropic or Orthotropic stress/strain behavior and as such the correct shear modulus is important. Hand layup FRP/GRP pipe construction typically follows isotropic stress/strain behavior similar to metallic piping where the shear modulus is a function of the longitudinal modulus and Poisson's ratio.

**B31.3 Method**

Select material library = AutoFRP.lib
For Thermoplastics, the method of determining HDS (Hydrostatic Design Stress) is described in ASTM D 2837. HDS values are given in Table B-1 of B31.3 for those materials and temperatures for which sufficient data have been compiled to substantiate the determination of stress. See B31.3 paragraph A302.3.2 (a).

For Reinforced Thermosetting Resin (Laminated), the design stress (DS) values for materials listed in Table B-2 of B31.3 shall be one-tenth of the minimum tensile strengths specified in Table 1 of ASTM C 582 or by the manufacturer and are valid only in the temperature range from -29°C (-20°F) through 82°C (180°F). See B31.3 paragraph A302.3.2 (b).

These can be entered under Tools> Combinations> Code combination.

Material library only has mechanical props no allowable stress, user allowable stress need to be entered. Add new load cases as shown below, and modify the allowable stress under Tools> Combinations> Code combination> Grid column; Allowable Stress.

**AUTOFRP Material Library (Use with B31.3):**

Pick AUTOFRP.lib material library on General Model options dialog. In addition, after entering the correct pipe size and wall thickness, select the appropriate pipe material from the drop down list on the Pipe Properties dialog; updating values as required (i.e. cold/hot allowable, Min yield, Ultimate, Yield). Or, use a custom material, see "Custom Materials" section below for details.
**Load Combinations**

First it is recommended to create several operating and occasional code combinations e.g:

- GR+P1+ (long) = cold sustained case,
- GR+T1+P1 + (long) = operating case
- GR+T1+P1+E1 + (long) i.e. operating + wind case 1

Where (long) is longitudinal pressure stress

Note: Para A319.1.2. does state ".no specific stress-limiting criteria or methods of stress analysis are presented.."

**Custom Materials**

**Option A.**

If a material is not available in the current library, select NS (non-standard) material (as shown below) from the “Pipe Material” drop down list and update the following values: Long. modulus, Hoop modulus, Shear modulus, Density, and Poisson's ratio.

In addition, when using “NS” material, update information on the Press/Temp/PipeID tab of the input grid (i.e. Expansion, Hot Modulus, Hot Allow, & Yield (Sy)).
Poisson's ratio defines the strain in the longitudinal direction caused by stress in the circumferential direction. For anisotropic materials, the strain in the circumferential direction caused by stress in the longitudinal direction is ignored. Orthotropic FRP material behavior follows this relationship:

\[ \frac{E_a}{E_h} \cdot \mu(h/a) = \mu(a/h) \]

where

- \( E_a \) = longitudinal tensile modulus
- \( E_h \) = Hoop tensile modulus
- \( \mu(h/a) \) = Poisson's ratio relating the strain in the axial direction due to a stress in the hoop direction

**Option B.**

Add custom material to AUTOFRP.lib material library as indicated in AutoPIPE’s online help. The following is a partial list of material properties required when adding a new material: longitudinal modulus, hoop modulus, shear modulus, density, Poisson's ratio, and table relating expansion modulus vs hot modulus vs temperature. Contact Bentley for source library.
BS7159 Method

Automatically defaults to component library = AUTOGRPP and material library = AUTOGRPM

Pipe Properties - select the laminate type and laminate ref. number, or use a custom material, see "Custom Materials" section below for details.

BS7159 Piping Code

Custom Materials

Option A

If a material is not available in the current library, select NS (non-standard) material (as shown below) from the “Pipe Material” drop down list and update the following values: Long. modulus, Circ modulus, Shear modulus, Density, and Poisson's ratio.

In addition, when using NS material, update information on the Press/Temp/PipeID tab of the input grid (i.e. Expansion, Hot Modulus, Hot Design Strain, & Temp. K-fac).
Option B

Add custom material to AUTOGRPM.lib material library as indicated in AutoPIPE’s online help. The following is a partial list of material properties required when adding a new material: longitudinal modulus, Circ. modulus, Shear modulus, Density, Poisson's ratio, and table relating expansion modulus vs hot modulus vs temperature. Contact Bentley for AUTOGRPM and/or GRPMFL1 source library. GRPMF1 contains pre-defined materials for Ameron pipe 5000C, 7000M, 2412C and 2420C/2420C-FP). Also request “General_ISO_Ameron_.xls” for more information.
**B31.8 Method**

AUTOFRP material library may be used with this piping code. Otherwise add a given material to AutoPIPE using traditional methods. In addition, when modeling non-metallic pipe materials with ASME B31.8 suggest that under Tools> Model Options> Results> “Deign Factor F: “ be set to 0.32.

The allowable is basically 0.32*Hydrostatic design stress. This can be used with hoop check. There are no such criteria for other stresses. For steel pipes design factor for hoop is usually 0.72 but depends on class of service. Also for steel pipes the longitudinal stress limit is 0.75Sy and for restrained pipe it is 0.90*Sy. Therefore a factor of 0.32 can be assumed for all stresses but could be conservative.

There are pressure and temperature limitations when modeling non-metallic piping. Suggest that a review of ASME B31.8 code, section 842 be conducted for complete details. Then apply these considerations to your AutoPIPE model on the “Press/Temp/Pipe” ID tab of the input grid.
842.2.1 Plastic Pipe and Tubing Design Formula.

The design pressure for plastic gas piping systems or the nominal wall thickness for a given design pressure (subject to the limitations in para. 842.2.2) shall be determined by the following formula:

(U.S. Customary Units)

\[ P = 25 \frac{t}{(D - t)} \times 0.32 \]

(SI Units)

\[ P = 20005 \frac{t}{(D - t)} \times 0.32 \]

where

- \( D \) = specified outside diameter, in. (mm)
- \( P \) = design pressure, psig (kPa)
- \( S \) = for thermoplastic pipe and tubing, long-term hydrostatic strength, psi (MPa), determined in accordance with the listed specification at a temperature equal to 73°F (23°C), 100°F (38°C), 120°F (49°C), or 140°F (60°C); for reinforced thermosetting plastic pipe, use 11,000 psi (76 MPa)
- \( t \) = specified wall thickness, in. (mm)

NOTE: Long-term hydrostatic strength at 73°F (23°C) for the plastic materials whose specifications are incorporated by reference herein are given in Mandatory Appendix D.

Furthermore suggest that for non-metallic pipes:

1. Bend flexibility is 1.0
2. Bend and Tee fittings have a minimum SIF of 2.3 (assumed).

Example:
Use AUTOFRP as library and enter hydrostatic design stress instead of yield.

### Table 842.2.9-1 Nominal Values for Coefficients of Thermal Expansion of Thermoplastic Pipe Materials

<table>
<thead>
<tr>
<th>General Material Designation</th>
<th>Nominal Coefficients of Thermal Expansion $\times 10^{-5}$ in./in./°F $\times 10^{-5}$ mm/mm/°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>PE 2306</td>
<td>9.0 (5.0)</td>
</tr>
<tr>
<td>PE 3306</td>
<td>9.0 (5.0)</td>
</tr>
<tr>
<td>PE 3406</td>
<td>9.0 (5.0)</td>
</tr>
<tr>
<td>PVC 1120</td>
<td>3.0 (1.7)</td>
</tr>
<tr>
<td>PVC 1220</td>
<td>3.5 (1.9)</td>
</tr>
<tr>
<td>PVC 2110</td>
<td>5.0 (2.8)</td>
</tr>
<tr>
<td>PVC 2112</td>
<td>4.5 (2.5)</td>
</tr>
<tr>
<td>PVC 2116</td>
<td>4.0 (2.2)</td>
</tr>
<tr>
<td>PB 2110</td>
<td>7.2 (4.3)</td>
</tr>
</tbody>
</table>

**GENERAL NOTES:**

(a) Individual compounds may differ from values in this table as much as ±10%. More exact values for specific commercial products may be obtained from the manufacturers.

(b) Abbreviations: PVC = polyvinyl chloride, PE = polyethylene, and PB = polybutylene.
In result options, set design factor and derating factors to 0.32. The design factor is used for hoop stress and derating factor (T) for other stresses.

**Notes:**

1. AutoPIPE will use allowable as 0.75*Sy*T for longitudinal stress and 0.9*Sy*T (tresca stress for restrained pipe)
2. Note that $S_c=0.33*S_u$, $S_h=0.33*S_u*T$.

3. The expansion data should be entered in in/100ft and is calculated as follows:
   a. Assume $a_{mb}=70$ and $T_1=100F$, so $D_T=30F$ and $\alpha=3.0E-5$ in/in/F
   b. Expansion = $\alpha D_T=3E-5*30*1200$ in/100ft = 1.08

4. For bends set user flex=1 and SIF=2.3. Same SIF for tees.

5. May have to assign a user allowable stress under Tools/Combinations set allowable stresses

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**Iso 14692 Method**

One of the features of AutoPIPE V8i 9.5 was adding a new Piping code: Iso 14692. This is a comprehensive code for modeling GRP / GRE materials. After selecting this code under Tool> Model Options> General, a unique set of fields which are specific to this piping code will be visible on the “Pipe Properties” and “Operating Press/Temp” dialog screen (see on line help for details on each field). For modeling purpose, complete the dialog with the required information. In addition, please see the following AutoPIPE help section for code calculation details:

Help > Contents> Contents Tab> Reference Information> Code Compliance Calculations> ISO 14692.
Frequently asked Questions

Q1 I cannot enter a coefficient of Thermal expansion for a non-standard pipe like in AutoPIPE v6.3?

Answer: The Coefficient of Thermal expansion was removed from the pipe properties screen in AutoPIPE 2004 since this was a constant value for all temperatures which is not correct and limiting for metallic and non-metallic piping.

Instead we introduced expansion rate e.g. in/100ft or mm/m on the pressure/temperature dialog such that different rates can be defined for different temperatures. If a Code or non-code material is defined for the pipe identifier then the program recovers these values automatically from the library but can be over-ridden. For NS materials just enter a expansion rate value.

Extract from AutoPIPE's online help

Expansion

This field and the corresponding Auto checkbox are used to input the thermal expansion data for each operating case. For non-standard (NS) materials, the thermal expansion data can be entered and modified. For standard and code materials, the field are not editable (grayed out) and the corresponding data is automatically retrieved from the material library for the appropriate temperature. For non-standard materials, the default value is zero for new models. For existing models with pipe identifiers defined with code or non-code materials then a new or existing pipe identifier changed to NS material will default to the previous expansion values. To override the automatic library value un-check the Auto option and enter the user-defined data.

Q2. Is the minimum yield value on the pipe properties screen relevant?

Answer: Correct Minimum yield is not relevant to FRP piping since it is brittle and not ductile material with only a breaking tensile strength limit.

So suggest enter zero value in this field.

Q3. Should I check the Pressure Analysis option when running a static analysis?

Answer: Yes it is important to consider axial stress and pressure analysis (since pressure expansion can be as much as thermal expansion and has self-limiting behavior like thermal loads)

Refer to Q43 and Q72 in AutoPIPE online help FAQ's
Q4. How do I model HDPE piping?

Answer: Either create a custom material library or use NS (non-standard) material and define the hoop, longitudinal, shear modulus, density, and Poisson's ratio for HDPE.

Important Note: HDPE properties vary with time and temperature therefore it is important to analyze model with 3-4 different properties to satisfy its performance over time.

Q5. What is meant by pseudo stress method?

Answer: Pseudo stress method is using B31.3 and FRP code section says take 1/10 of the tensile stress as a limit of stress as described above.

Users will need to enter in allowable stress, as the material library only has mechanical properties; i.e. no allowable stresses.

Q6. How does AutoPIPE consider the Poisson's ratio for anisotropic materials?

Answer: Pipe stress programs like AutoPIPE and CAESAR are based on 1-D beam finite elements and can capture orthotropic material behavior assuming the pipe has 2 orthogonal planes of symmetry which is reasonable assumption for hand lay-up or spiral wound FRP manufactured pipes. Bentley's AutoPIPE program has a more advanced non-linear engine for load sequencing, friction and gap analysis. However to capture anisotropic properties (no planes of symmetry) you would need a true 3D finite element model and program like ANSYS.

For anisotropic material behavior, the hoop Poisson's ratio is ignored, i.e. not calculated nor used. When we calculate the hoop stress, it ignores any additional hoop stress caused by strain in the longitudinal direction. This assumption is usually conservative, since the stress caused by the hoop Poisson's ratio could mitigate the hoop stress caused by pressure alone. Furthermore, the stiffness matrix that we have in our analysis engine assumes orthotropic material.

Please see the FRP_ISO14692_Ameron_x.xls, Template PipeID worksheet for more information.

Q7. What parameters need to be set for modeling HDPE PE100 plastic piping using ASME B31.3 method?

Answer: If you are working with AutoPIPE V8i v.9.4.1.5 or lower, the following inputs would require to be changed:

- Pipe properties: OD, Thickness, erosion allowance, density, long modulus, hoop modulus, cold allowable
- Pressure & Temperature: Hot modulus, Poisson's ratio, hot allowable, expansion value
- Under ground loading: Traffic load and earth load would require to be handled separately.
- SIF values, flexibility factors would require to be handled.

In the upcoming version 9.6, we are adding ASME code case N-755-1 which specifically deals with HDPE piping.
Q8. Are there any methods that use the B31.1 Code?

**Answer:** Yes, similar design approach for B31.1 as B31.3 - refer to non-mandatory appendices.

Q9. I have to input Shear Modulus, Long Modulus, Hoop Modulus, and Hot Modulus. I know that Shear Modulus. Where do I get these values?

**Answer:** Plastic pipe moduli are different for hoop and axial directions. Plastic materials do vary so much based on their composition and structure. The Poisson ratio also varies and typically you enter the larger value in AutoPIPE and the other is obtained by multiplying with the ratio of the two moduli. What that means is that you enter larger Poisson ratio and AutoPIPE calculates the smaller one by using hoop and long modulus ratio. Your only source for data is your manufacturer. Hot modulus should also be provided by the manufacturer.

Q10. Is the AutoPIPE program suitable for non-metallic pipes and if the code stress is adapted for this?

**Answer:** In general, if the properties defined are correct, you would expect to get correct results. However, there may be other design guidelines provided by the design code which would require to be incorporated. For example, in AutoPIPE version 9.5 we added ISO 14692, for which the code requires calculations which are different to metallic piping.

Q11. For underground piping, is the depth of soil loaded on the pipe?

**Answer:**
For AutoPIPE 9.4.1.5, the soil stiffness values calculator was enhanced to facilitate the user for calculation of these values automatically. The soil depth would not be loaded on to the pipe.

In AutoPIPE V8i v9.5 and higher, we have added buried piping stresses based on Adams et al. method which allows the user to check circumferential compressive stress caused by soil and traffic loads. This stress can be added to the sustained stress, and is done so automatically for B31.1.
Q12. How can I input different Hoop and Long. Stress allowable?

Answer:

AutoPIPE XM 9.0 and lower:

![Image of AutoPIPE XM user interface showing allowable stress input]

AutoPIPE V8i 9.1 and higher:

Unlike the older version, AutoPIPE V8i 9.1 and higher can only enter 1 allowable stress per a combination. One of our customers, IDE Technologies, conservatively based on Allowable Axial (longitudinal) stress. Since governing BS7159 stress will be either Hoop or Longitudinal stress whichever is highest.

The CAE development team will be adding ISO14692 design code in AutoPIPE V8i v9.5. This will have failure envelope i.e. checking both Hoop and Longitudinal calculated stresses vs allowable hoop and longitudinal stresses.

Therefore the single BS7159 Allowable stress is simplified method for ISO 14692 since the combined stress for BS7159 is the maximum of combined Hoop or Longitudinal stress (bends and straight pipe).