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Ductile Iron Pipe
Research Association

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MATERIAL COMPARISONS

Ductile Iron Pipe vs. HDPE Pipe

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There are a myriad of factors that design engineers consider when designing and specifying a potable water pipeline: initial cost of the system, operating requirements, maintenance costs, dependability, and long-term performance.

This brochure compares the short- and long-term structural and performance attributes of Ductile Iron Pipe and high-density polyethylene (HDPE) pipe. It provides valid current information to engineers who determine a basis for selecting piping materials.

In addition to providing physical test data comparing the two pipe products, this brochure also compares applicable AWWA design standards for each pipe (ANSI/AWWA C150/A21.50[1] for Ductile Iron Pipe and ANSI/AWWA C906[2] for HDPE pipe).

The following data is drawn from several sources, including American Water Works Association (AWWA) standards, published information from pipe manufacturers and associations, and physical testing from the Ductile Iron Pipe Research Association, Structural Composites Inc. and Plastics Engineering Laboratory.[3] The tests reported in this brochure were conducted on 6-inch and 24-inch diameter Ductile Iron and HDPE pipe. The lowest Pressure Classes available for 6-inch and 24-inch diameter Ductile Iron Pipe (350 psi and 200 psi respectively) were used. The HDPE pipe consisted of DR9 and DR11 pipe made from PE 3408 HDPE material. This material is the highest rated material in ANSI/AWWA C906. The DR of a pipe is the quotient of its outside diameter divided by its average wall thickness. Therefore, the lower the DR, the thicker the pipe wall. The low DR (higher pressure) HDPE pipes were selected in an effort to, as closely as possible, compare equivalent rated pipe. DR9 (200 psi) and DR11 (160 psi) HDPE pipe were the lowest DRs available when the pipe was purchased. Higher DR HDPE pipe, which is sometimes specified, would be much weaker.

This brochure presents sound engineering information that will prove that all materials are not equal.

TABLE 1
Comparison of Ductile Iron Pipe and HDPE Pipe Standards

TOPIC	Ductile Iron Pipe ANSI/AWWA C150/A21.50 ANSI/AWWA C151/A21.51	HDPE Pipe ANSI/AWWA C906
Sizes	3"– 64"	4" – 63"
Laying Lengths	18', 20'	40'
Pressure Class/Ratings	Rated up to 350 psi. Pressure Class 150, 200, 250, 300, & 350. Higher pressures may be designed.	Dependent on material code: 40 to 198 psi for PE 2406 or PE 3406; 51 to 254 psi for PE 3408. Rated up to 254 psi for 20-inch diameter and smaller. Due to manufacturers' limited extrusion capabilities for wall thicknesses >3-inches, ratings may be progressively reduced with increasing sizes greater than 20-inches in diameter.
Method of Design	Designed as a flexible conduit. Separate design for internal pressure (hoop stress equation) and external load (bending stress and deflection). Casting tolerance and service allowance added to net thickness.	Flexible material; internal pressure design only. **External load design is not covered by a standard.**

TABLE 1 (Continued)
Comparison of Ductile Iron Pipe and HDPE Pipe Standards

TOPIC	Ductile Iron Pipe ANSI/AWWA C150/A21.50 ANSI/AWWA C151/A21.51	HDPE Pipe ANSI/AWWA C906
Internal Design Pressure	Pressure Class: stress due to working pressure plus surge pressure cannot exceed the minimum yield strength of 42,000 psi ÷ 2.0 safety factor.	Pressure Rating: Stress due to working pressure cannot exceed the Hydrostatic Design Basis (1,600 psi) Ð 2.0 safety factor (Hydrostatic Design Stress = 800 psi) for PE 3408. **Any surge pressure compromises the safety factor.**
Surge Allowance	Nominal surge allowance is 100 psi (based on an instantaneous velocity change of approximately 2 fps), however, actual anticipated surge pressures should be used.	**Not Included.** Surge pressures are allowed to compromise the "design factor" which results in a reduction in the safety factor below 2.0.
External Load Design	Prism load + truck load. Ring bending stress limited to 48,000 psi, which is 1/2 the minimum ultimate bending strength. Deflection is limited to 3% of the outside diameter of the pipe, which is 1/2 of the deflection that might damage the cement-mortar lining. The larger of these two thicknesses governs and is taken as the net thickness.	**None discussed in standard.**
Live Load	AASHTO H20, assuming a single 16,000 lb. concentrated wheel load. Impact factor is 1.5 for all depths.	**None discussed in standard.**
Factor of Safety	**Pressure Design:** 2.0 (including surge) based on minimum tensile yield strength of 42,000 psi. **External Load Design:** 2.0 for bending based on minimum ultimate ring bending strength of 96,000 psi, or 1.5 for bending based on minimum ring yield bending strength of 72,000 psi. 2.0 for deflection for cement-mortar-lined pipe. **Note:** Actual safety factors are greater than the nominal safety factors due to the addition of the service allowance and casting tolerance in the design procedure.	A "Design Factor" is used in the internal pressure design formula. This factor is simply the inverse of the more common "Safety Factor." This "Design Factor," in reality, is not a constant number. The design formula for HDPE pipe ignores surge pressures by merely increasing the "Design Factor," thereby, reducing the "Safety Factor," to compensate for them. **Ignoring surge pressures, the "Design Factor" is 0.5 ("Safety Factor" is 2.0). Acknowledging surge pressures, the "Design Factor" is >0.5 ("Safety Factor" is < 2.0).**
Specified Trench Conditions	Five specified laying conditions (Types 1-5). Conservative E' and soil strength parameters listed. Type 1 (flat bottom trench, loose backfill) or Type 2 (flat bottom trench, backfill lightly consolidated to centerline of pipe) are adequate for most applications.	**None.**
Hydrostatic Testing	Each pipe tested to a minimum of 500 psi for at least 10 seconds at full pressure.	Only one pipe size from three size ranges (4- to 12-, 14- to 20-, and ≥ 24-inch) are subjected to an elevated temperature sustained pressure test **semiannually**. Also, only one pipe per production run **may be** subject to a quick burst test. A ring tensile test or a five-second pressure test can be substituted for this test.
Factory Tests	At least one sample during each casting period of approximately 3 hours shall be tested for tensile strength; must show minimum yield of 42,000 psi, minimum ultimate of 60,000 psi and a minimum elongation of 10%. At least one Charpy impact sample shall be taken per hour (minimum 7 ft-lb.), with an additional low-temperature impact test (minimum 3 ft-lb.) made from at least 10% of the sample coupons taken for the normal Charpy impact test.	Bend-back or elongation-at-break; once per production run. Ring tensile, quick burst, or five second pressure test; once per production run. Melt flow index; once per day. Density; once per day. Carbon black content; once per production run.

The preceding table compares the requirements of ANSI/AWWA C150/A21.50 and ANSI/AWWA C151/A21.51[4] to ANSI/AWWA C906.

Ductile Iron Has More Than 24 Times The Tensile Strength Of HDPE Pipe

A pipe material's tensile strength is a very important basic property because it resists the forces caused by internal hydrostatic pressure and water hammer.

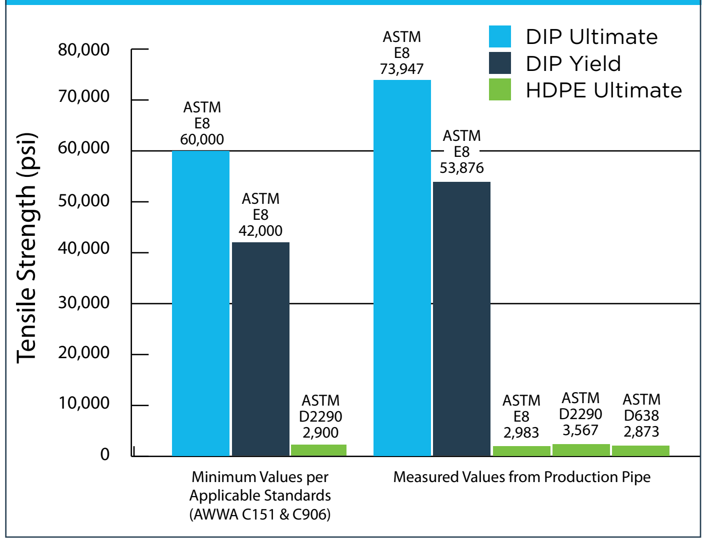
Figure 1 compares the tensile strength of Ductile Iron and HDPE pipe. Shown for comparison are minimum values per the applicable standards as well as test data from specimens taken from the wall of 6-inch Pressure Class 350* Ductile Iron Pipe, and 6-inch DR 11 (160 psi) HDPE pipe. All pipe materials were tested in accordance with ASTM E8.[5] In addition, the HDPE pipe was tested in accordance with ASTM D2290[6] and ASTM D638.[7] ANSI/AWWA C151/A21.51 specifies that the ultimate tensile strength, yield strength and elongation of Ductile Iron Pipe be determined in accordance with ASTM E8. AWWA C906 specifies that the ultimate tensile strength of HDPE pipe be determined in accordance with ASTM D2290 and its elongation be determined in accordance with ASTM D638.

The tensile strength values for HDPE in Figure 1 represent "short term values." "Long term values" would be much less. Unlike Ductile Iron, HDPE experiences "tensile creep," even at relatively low stress levels. As the rate of loading on HDPE is decreased, or when HDPE is subjected to a constant load over a longer period of time, the molecules have time to disentangle, which will lower the stress needed to deform the material.[8]

*Pressure Class 350 is the lowest available pressure class for 6-inch Ductile Iron Pipe.

FIGURE 1

Tensile Strength



Typical Variations In Operating Or Installation Temperature Do Not Affect The Strength Of Ductile Iron Pipe

Since Ductile Iron Pipe has a moderate and dependable coefficient of thermal expansion, few problems are created by changes in service temperatures. Ductile Iron shows no significant difference in tensile strength in a typical range of waterworks operating temperatures (32°F to 95°F) or even a conceivable extreme range of installation temperatures (-10°F to 140°F).

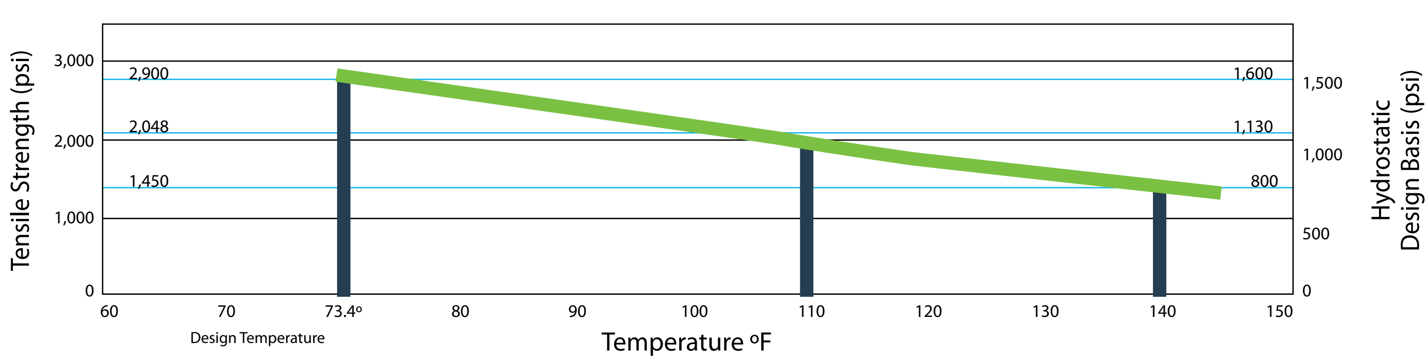
Because of HDPE pipe's thermoplastic polymeric nature, its performance is significantly related to its operating temperature.[9] An indication of this is that HDPE manufacturers do not recommend their products for pressure service above 140°F.[10] In addition, for service at temperatures greater than 73.4°F, HDPE loses tensile strength, pipe stiffness, and dimensional stability. The pressure capacity of the HDPE pipe is reduced, and more care must be taken during installation to avoid excessive deflection.

Because the thermal expansion coefficient of HDPE is approximately 18 times that of Ductile Iron Pipe,[11] it is conceivable that, when exposed to extreme temperature changes, HDPE will experience undesirable structural movements.

Figure 2 shows the relationship based on the standard tensile strength of 2,900 psi and the Hydrostatic Design Basis (HDB) of 1,600 psi for HDPE pipe. At 110°F, the tensile strength and HDB of HDPE is approximately 70 percent of the tensile strength and HDB at 73.4°F and only half (50 percent) of those amounts at 140°F. This reduction in strength has to be incorporated into the design of HDPE pipe.

FIGURE 2

Strength Relationship for HDPE



Ductile Iron Pipe Resists Up To 6.1 Times The Hydrostatic Burst Pressure Of HDPE Pipe

The burst test is the most direct measurement of a pipe material's resistance to hydrostatic pressure. Tests were conducted in accordance with ASTM D1599[12] by fitting the pipe specimens with gasketed, unrestrained end caps and securing them in a hydrostatic test structure to resist the end thrust. This arrangement produced stresses primarily in the circumferential direction in the walls of the pipes as internal hydrostatic pressure was applied.

All of the Ductile Iron Pipe specimens (6- and 24-inch diameter) burst in the form of a fracture 15- to 41-inches long.

All of the HDPE specimens (6- and 24-inch diameter) failed by "ballooning" with some also bowing and snaking, causing the pipe to pull away from the end closures and leak at the test seals. The use of blocking and tie downs in conjunction with short sections of pipe were unsuccessful in restricting the movement of the HDPE pipe. This illustrates the difficulties in achieving dependable mechanical jointing of HDPE pipe. Ballooning of the pipe caused permanent deformation in every specimen tested. The permanent increase in diameter* of the HDPE specimens (after release of the internal pressure and removal from the hydrostatic test structure) are shown in Table 2.

*NOTE: Under higher pressures, the diameter would have been even greater.

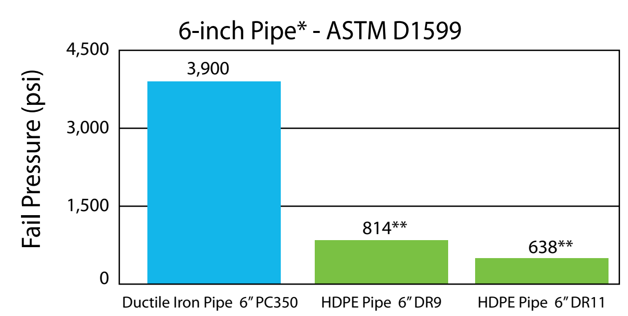
Figures 3 and 4 compare the average hydrostatic burst pressure (Ductile Iron Pipe), and failure due to ballooning pressure (HDPE pipe). Note that Ductile Iron Pipe is available in pressure classes up to 350 psi in all sizes, 3-inch to 64-inch. Additionally, including the standard 100 psi surge pressure allowance, Pressure Class 350 Ductile Iron Pipe has a pressure rating of 450 psi. No HDPE pipe is manufactured with a pressure rating as great as that of Ductile Iron Pipe.

TABLE 2

HDPE Specimens	Permanent Increase in Diameter
6-inch DR11	4.51% to 13.12%
6-inch DR9	1.06% to 8.87%
24-inch DR11	2.46% to 2.63%
24-inch DR9	2.09% to 11.60%

FIGURE 3

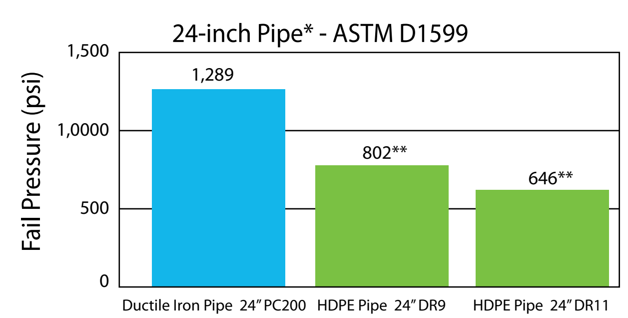
Hydrostatic Burst Test



*DIP with a 6.9-inch outside diameter and HDPE with a 6.625-inch outside diameter.
**Burst pressure at which HDPE pipe failed by ballooning.

FIGURE 4

Hydrostatic Burst Test



*DIP with a 25.8-inch outside diameter and HDPE with a 24.0-inch outside diameter.
**Burst pressure at which HDPE pipe failed by ballooning.

The Strength Of Ductile Iron Pipe Is Not Compromised By Time

There is no measurable relationship between Ductile Iron's applied tensile strength and time to failure. Therefore, the strength for hydrostatic design of Ductile Iron Pipe is its minimum yield strength in tension, 42,000 psi.

HDPE responds to tensile stress by failing after a period of time inversely related to the applied stress. That means the strength used for hydrostatic design of HDPE pipe is less than the yield strength of the material as established in a short time test.[13] The strength value used is called the Hydrostatic Design Basis (HDB).

The HDB value, which is defined as the stress that results in failure after 100,000 hours (11.4 years), is determined according to ASTM standard procedures by extrapolation from data accumulated from tests lasting up to 10,000 hours (1.14 years).[14] For AWWA C906 pipe, the HDBs are 1,250 psi (PE 2406 and PE 3406) and 1,600 psi (PE 3408). PE 3408 was used in tests conducted for this brochure. The HDB will be less than 1,600 psi for HDPE pipe used at temperatures greater than 73.4°F.[15]

FIGURE 5

Typical Creep Rupture Curve for HDPE Pipe

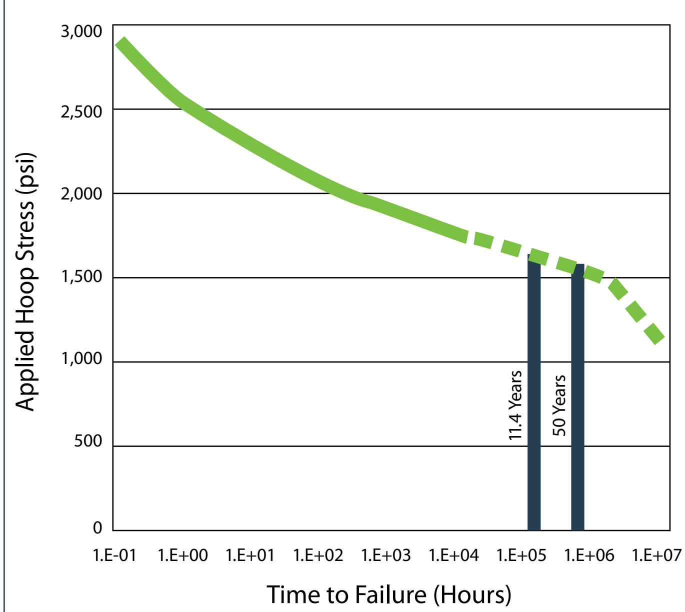


Figure 5 shows a typical creep rupture curve for HDPE pressure pipe depicting the relationship between applied stress and time to failure. Note that after 11.4 years, HDPE fails under approximately 55 percent of the stress that will cause failure initially. The stress-rupture line for HDPE shown in Figure 5 can have a downturn or "knee" where the failure mode changes from ductile to brittle. This mode of failure is referred to as brittle or slit failure due to the formation of cracks or small pin holes within the pipe wall. These types of failures are the results of the manifestation of fracture mechanics mechanism, which involves crack formation, propagation, and ultimate failure. This is the type of HDPE pipe failure generally seen in the field.[16]

The Long Term Crushing Load Of Ductile Iron Pipe Is Up To 82 Times Greater Than HDPE Pipe

The different theories of design of buried pipelines become most significant in relation to external load design. Ductile Iron Pipe and HDPE pipe, being flexible rings, respond to external load by deflecting. The interaction of the deflected ring with the surrounding soil is the complex question in the design theories.

The design procedure in ANSI/AWWA C150/A21.50 for external loads on Ductile Iron Pipe is based on limiting both the ring bending stress and deflection. External load design is not addressed in ANSI/AWWA C906; however, generally the only parameter used in the design of HDPE pipe is ring deflection.

While utilizing conservative assumptions regarding soil parameters and earth loads, the standard design procedure for Ductile Iron Pipe limits the ring bending stress to 48,000 psi, which is one-half its minimum ultimate bending strength.

The design procedure for Ductile Iron Pipe also limits the ring deflection due to external loads to 3 percent. This limit, which is based on the performance limit for cement-mortar linings typically specified for Ductile Iron Pipe, includes an explicit safety factor of 2. This calculation employs the same conservative assumptions regarding soil parameters and earth loads used in the bending stress calculation.

Deflection limits of HDPE pipe are normally based upon no more than 1 1/2 percent strain in the extreme fibers of the pipe section. Due to the relatively thick pipe wall sections of low DR pipe, low deflection limits are established. Poly Pipe Industries recommends a maximum of 2.5 percent deflection for DR9 HDPE pipe and 3.0 percent deflection for DR11 pipe.[17] Exceeding 10 percent deflection results in pipe crown instability tending toward inversion collapse.

In the case of Ductile Iron Pipe, the conventional tensile test is relied upon to define basic mechanical properties such as modulus of elasticity, proportional limit, and yield strength. These basic properties are used in the many design equations that have been developed based upon elastic theory, where strain is always assumed to be proportional to stress. With plastics there is no such proportionality. The relationship between stress and strain is greatly influenced by duration of loading, temperature, and environment. The values of the modulus of elasticity, yield strength, ultimate strength, and other short-term properties of plastics are for defining and classifying materials. Strength and stiffness values that have been determined by means of short-term tests are not suitable constants for use in the large body of equations that have been derived on the assumption of elastic behavior. However, most of these equations can be, and are, used with plastics provided their strength and rigidity are defined by property values that give consideration to their non-elastic behavior.[18]

Laboratory ring crush tests of HDPE pipe conducted with a rapid 0.5 radial inch-per-minute ring loading rate are meaningless due to its inherent creep. The material property which ring stiffness is dependent on is the modulus of elasticity. When HDPE is stressed, its modulus of elasticity decreases with time. For example, for a 50-year life expectancy, the modulus of elasticity of HDPE decreases from its short-term range of 100,000 — 30,000 psi to a long-term range of only 20,000 — 30,000 psi.[19] Taking this into account, small diameter Pressure Class 350 Ductile Iron Pipe has approximately 82 times the long term ring stiffness of DR9 HDPE pipe. Therefore, achieved soil stiffness, bedding conditions, and on-the-job installation inspection are obviously much more critical with HDPE pipe because it has much less long-term pipe stiffness than Ductile Iron Pipe.

Table 3 compares the calculated stiffness of HDPE pipe, based on a long-term modulus of elasticity of 25,000 psi, to that of Ductile Iron Pipe. The table reflects HDPE DR9 pipe for sizes 4-inch through 24-inch diameter. In sizes 30-inch through 54-inch diameter, the wall thickness of HDPE was limited to 3 inches due to potential production limitations as stated in ANSI/AWWA C906. All Ductile Iron Pipe in Table 3 represents the minimum Pressure Class available.

TABLE 3
Pipe Stiffness

Pipe Size*	DUCTILE IRON PIPE		HDPE	
	Pressure Class (psi)	Pipe Stiffness (psi)	DR (Pressure - psi)	Pipe Stiffness (psi)
4	350	17,812	9.0 (200)	218
6	350	5,705	9.0 (200)	218
8	350	2,462	9.0 (200)	218
10	350	1,482	9.0 (200)	218
12	350	1,093	9.0 (200)	218
14	250	696	9.0 (200)	218
16	250	580	9.0 (200)	218
18	250	453	9.0 (200)	218
20	250	401	9.0 (200)	218
24	200	234	9.0 (200)	218
30	150	133	11.0 (160)	112
36	150	108	13.5 (128)	57
42	150	86	15.5 (110)	37
48	150	82	17.0 (100)	27
54	150	77	21.0 (80)	14

*ANSI/AWWA C906 only lists 4–inch through 54–inch diameter HDPE with Ductile Iron equivalent O.D.'s

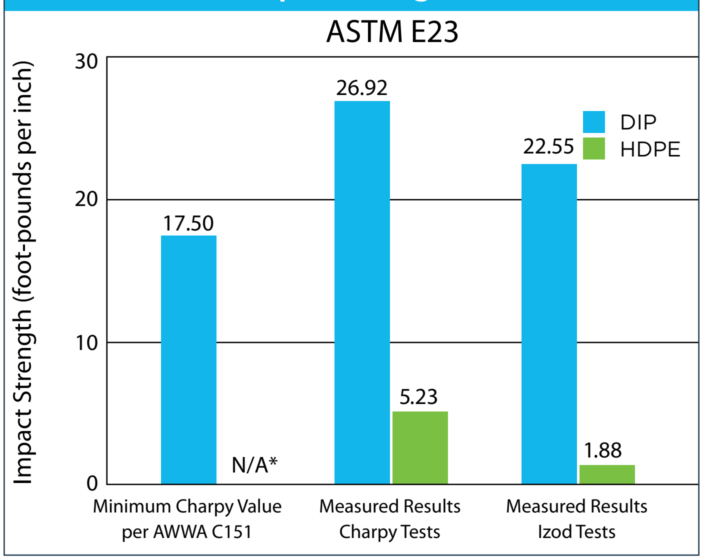
Ductile Iron Has Up To 12 Times More Impact Strength Than HDPE

Impact strength is another important characteristic of piping materials. This property relates more to conditions the pipe might encounter during handling, shipping, and installation, but it can also be important if future work is conducted around an operating pipeline. It is critical because damage incurred during these activities can go undetected and result in failures in the operating pipeline.

Figure 6 compares the impact strength as specified and measured for Ductile Iron to that measured for HDPE (impact strength is not specified in ANSI/AWWA C906 for HDPE pipe). Tests were conducted by both the Izod (cantilevered beam) and Charpy (simple beam) methods.[20] These values are representative of tests conducted at 70° ± 310°F. As with tensile strength, there is no measurable relationship between impact-resistance and expected installation and operation temperature ranges for Ductile Iron Pipe.

FIGURE 6

Impact Strength



* AWWA C906 (HDPE) contains no minimum impact strength values.

Direct-Tapping Ductile Iron Pipe Is Easier, Less Expensive and Faster Than Tapping HDPE Pipe

Service taps are easily made either before or after Ductile Iron Pipe installation. The procedure simply involves strapping on the tapping machine, drilling/tapping the pipe, and inserting the corporation stop. The minimum Pressure Class of all diameters of Ductile Iron Pipe may be direct tapped for 3/4-inch services. Additionally, the minimum Pressure Class of 6-inch and larger Ductile Iron Pipe may be direct tapped for 1-inch services. Standard corporation stops can be used on all Pressure Classes of Ductile Iron Pipe and can be screwed directly into the tapped and threaded pipe.

Unlike Ductile Iron Pipe, direct threading of polyethylene pipe is not recommended. Sidewall fusion is used to install service connections on HDPE pipe. The Plastics Pipe Institute recommends that sidewall-type fusion joints be made only with a mechanical assist tool.[21] The fusion process requires a saddle fusion machine, heater saddle adapters, heater plate, AC power source, surface temperature measuring device, utility cloth, denatured alcohol, a sidewall fusion fitting, and should probably not be done even in emergencies in wet or dirty (rain, etc.) conditions without enclosures. There are eight sequential steps published in the Plastics Pipe Institute brochure "Polyethylene Joining Procedures"[21] that are normally used to create a saddle fusion joint. They are:

1. Clean the pipe - Remove any dirt or coating. .
2. Install the heater saddle adapters - Install the saddle adapters on the heater plate being careful not to overtighten and ensuring that the surfaces are clean and flush (any dirty or rough surface will retard and limit heat transfer and thereby affect joint integrity). Allow the heater to come to the specified temperature [this will take several minutes].
3. Install the saddle fusion machine - Use manufacturer's instructions to straighten and round the pipe using caution not to flatten the pipe.
4. Prepare surfaces - Remove any contaminants and use a grit utility cloth (sandpaper or other abrasive materials are likely to leave grit or deposits of other foreign materials on the pipe surface) to clean and roughen the pipe surface and fitting saddle contour to expose fresh material. [Clean the surfaces with denatured alcohol.]
5. Fitting alignment - Inspect to ensure a precise fit to the pipe.
6. Heating - Check the heater temperature periodically to verify the proper surface temperature using a pyrometer or other surface temperature measuring device. Place the heater tool in position to heat the pipe and fitting surfaces following the manufacturers' instructions carefully.

7. Fusion - After the prescribed heating requirements have been met, remove the heater from the heated pipe and fitting surfaces and quickly inspect the melt pattern on both the fitting and the pipe. Join the fitting to the pipe with the prescribed fusion force.
8. Cooling - Continue to hold the force during the cooling cycle. Allow the joint to cool to ambient temperature [this may take approximately 30 minutes]. Do not subject the joint to any external stresses until the fusion joint has cooled. After it has cooled, cut the service hole in the pipe.

No reference could be found to verify if it is or is not recommended to install service taps in HDPE pipe under pressure. Verbal recommendations from manufacturers and users varied.

Tapping Ductile Iron Pipe is easier, less expensive and faster than tapping HDPE.

Energy Savings

Ductile Iron Pipe's larger inside diameter results in significant energy savings, whether the savings are based on pumping costs or equivalent pipeline considerations.[22]

Utilities save appreciably on power costs and continue to save money every year for the life of the pipeline due to Ductile Iron's larger than nominal inside diameter and lower pumping costs.

By using equivalent pipeline theories, utilities can realize immediate savings with Ductile Iron Pipe. Because of Ductile Iron's lower head loss, substitute pipelines with equivalent head loss would require larger — and more expensive — pipe diameters over portions of the pipeline.

For example, a 30,000-foot-long, 24-inch Pressure Class 200* Ductile Iron Pipeline delivering 6,000 gallons per minute has the same total head loss as 1,556 feet of 24-inch DR9 (200 psi), plus 28,444 feet of 30-inch DR9 (160 psi) HDPE pipe, even when less proven, more liberal flow coefficients are assumed for the HDPE pipe.

Conversely, a Ductile Iron Pipeline could be designed to produce the same head loss as a substitute pipeline. The Ductile Iron Pipeline, however, would require smaller — and, thus, less expensive — pipe diameters over portions of the pipeline. For the same example above, 30,000 feet of 24-inch DR9 HDPE pipe would have the same total head loss as 27,231 feet of 20- inch** Pressure Class 250* Ductile Iron Pipe plus 2,769 feet of 18-inch** Pressure Class 250* Ductile Iron Pipe.

OTHER CONSIDERATIONS

Permeation

HDPE is highly permeable and should not be laid in contaminated land or in land on which hydrocarbons, including crude and fuel oils, gasoline, diesel fuel, and kerosene or the constituents of any of these hydrocarbon mixtures are used or stored. These chemicals can solvate and permeate into the walls of polyethylene and other plastic pipes, potentially swelling and weakening the pipe and/or adversely affecting the taste and/or odor of the potable water conveyed.

Unlike HDPE, Ductile Iron Pipe does not deteriorate and is impermeable when subjected to hydrocarbons. With Ductile Iron Pipe systems, only the gasketed joints may be subjected to permeation. However, due to the gasket's large mass and the relatively small contact area between the gasket and soil, permeation through Ductile Iron Pipe gasketed joints is not likely to be a significant source of contamination unless the gasket is exposed to neat organic chemicals for long periods of time. This is evidenced in the report titled, "Permeation of Plastic Pipes by Organic Chemicals," by Jenkins of the University of California, Berkeley, and published in the August 1991 issue of Journal AWWA under the title "Contamination of Potable Water by Permeation of Plastic Pipe."[23] The results of an extensive literature search, together with a survey of U.S. water utilities, revealed in this report that plastic pipe was the major piping material involved in permeation incidents with polybutylene, polyethylene, and polyvinyl chloride accounting for 43, 39, and 15 percent respectively of all the incidents reported. No incident of permeation of Ductile Iron Pipe and only one incident of permeation of a gasket (type of pipe was not disclosed) was reported.

* The minimum pressure class available for that diameter pipe.
** Due to the **much** smaller than nominal inside diameter of 24-inch HDPE pipe, the equivalent Ductile Iron Pipeline was constructed of 18- and 20-inch pipe.

Some gasket materials resist permeation and degradation from hydrocarbons better than others. While tests on other gasket materials show promise, the results to date indicate that fluorocarbon rubber gaskets are the most resistant to permeation. Gaskets of this material are available for use with Ductile Iron Pipelines installed in areas contaminated by or susceptible to contamination by hydrocarbons.

Bedding Requirements

Due to the inherent weaknesses in HDPE pipe, bedding conditions are much more critical than with Ductile Iron Pipe. Proper bedding is required to control deflection, which is the single criterion in design of HDPE pipe for external loads. Standards dealing with recommended installation practices for plastic piping suggest that the pipe be surrounded by a soil with a minimum particle size, which is dependent on the pipe diameter, so that the soil can be sufficiently compacted to develop uniform lateral passive soil forces.[24] The soil also must be free of organic matter. The trench bottom must be smooth and free from large stones, large dirt clods, and any frozen materials, as these objects could cause a reduction in strength due to scratches or abrasions.[25] Such special bedding requirements are not practical or actually realized in many areas.

Because of Ductile Iron Pipe's inherent strength, Type 1 (flat bottom, loose backfill) or Type 2 (flat bottom, lightly consolidated backfill) — essentially native trench conditions in accordance with ANSI/AWWA C150/A21.50 — are adequate for the vast majority of applications.

Joining and Joint Deflection

Thermal butt-fusion is the most widely used method for joining HDPE pipe and requires personnel who have received training in the use of the fusion equipment according to the recommendations of the pipe supplier or the equipment supplier. This time-consuming method requires expensive field equipment to hold the pipe and/or fitting in close alignment, melt the pipe, and join the pipe with the correct loading. Buttends have to be faced, cleaned, melted, and fused together, then cooled under fusion parameters recommended by the pipe and fusion equipment supplier. The process also produces a double-roll melt bead on the inside (restricting flow) and the outside of the pipe, both of which sometimes may need to be removed. In situations where different polyethylene piping materials must be joined, both pipe/fitting manufacturers should be consulted to determine the appropriate fusion procedures. The training and equipment needed to fuse the pipe and service a system requires a costly expenditure. Even with the right equipment (fusion machines, generators, repair components, etc.), variabilities in the weather, or soil conditions, or even the slightest error in the fusion procedure can make maintaining a HDPE system excessively difficult. Expansion and contraction problems are also common, as are problems created by the pipe's dimensional variance and tendency to "egg." Fusion equipment is expensive and difficult to maintain and requires operator competence that may be difficult to staff and too expensive to employ for most utilities. Since the butt-fusion joint is rigid, curves require special fittings or actual deflection of the pipe itself, which places stress (perhaps often not appropriately considered in the design) in the pipe wall. The 40- and 50-foot lengths of HDPE pipe can create logistical and equipment challenges in the field. Long exposed open trenches can also create safety concerns and business obstructions.

The push-on joint is the most prevalent joining system for Ductile Iron Pipe systems. It simply requires lubrication of the joint gasket and pushing the plain end into the bell end of the pipe. Ductile Iron Pipe joining has an excellent record of performance with installation by all kinds of labor and equipment and in all kinds of conditions, including dirty and underwater installations. With Ductile Iron Pipe, no joint or pipe barrel stress is required to obtain sufficient deflection. Depending on pipe diameter, push-on joint Ductile Iron Pipe has a joint deflection of up to 5°.[26] Ductile Iron Pipe fitted with ball and socket joints has a maximum deflection of up to 15° per joint in sizes up to and including 24-inch pipe; in sizes 30-inch and larger, maximum deflection varies from 12.5° to 15°.[27]

Fittings

Ductile Iron Pipe fittings are manufactured in accordance with ANSI/AWWA C110/A21.10 "Ductile-Iron and Gray-Iron Fittings 3 In. Through 48 In. For Water," and ANSI/AWWA C153/A21.53 "Ductile-Iron Compact Fittings, For Water Service." The rated working pressure (up to 350 psi) of standard fittings depends on the material (Gray Iron or Ductile Iron), the fitting size and configuration, and the wall thickness. The wide range of designs available in Ductile Iron pressure piping systems results, in part, from the ready availability of a great variety of fittings. The ability to go around or bypass unexpected obstacles encountered in the planned course of a line by cutting the pipe in the field and installing the appropriate fittings has long been recognized as an advantage of iron pipe systems. The available configurations vary between the two standards, with bends, tees, crosses, reducers, and sleeves available from each; while base bends, base tees, caps, plugs, offsets, connecting pieces, and tapped tees are covered only by the C110/A21.10 standard. Special fittings such as long radius fittings, reducing elbows, reducing on-the-run tees, side outlet fittings, eccentric reducers, wall pipe, welded-on bosses and outlets, dual purpose and transition sleeves, and lateral and true wyes are also available from some manufacturers.

Most fittings for HDPE pipe are fabricated, and manufacturers typically recommend a derating factor of 25% for any fabricated fitting which requires a miter joint (bends and tees). Distributors may not provide the fully pressure rated fitting unless the specifications specifically require doing so. In a DR11 (160 psi working pressure) HDPE pipe system, DR11 mitered fittings are only rated for 120 psi, and DR9 mitered fittings for only 150 psi. Therefore, DR7.3 mitered fittings would be required to assure at least equal pressure rating with the pipe. This presents a problem. For example: 16-inch diameter HDPE (DIOD) DR11 and DR7.3 have average inside diameters of 14.05-inches and 12.35-inches respectively. The effective flow area of the DR7.3 fitting is 23% less than the DR11 pipe. Also, there is no agreement between the HDPE pipe manufacturers that pipe of such different wall thicknesses may be effectively joined by heat fusion. There are no universally accepted procedures for fusing HDPE pipe materials with wall thickness differentials greater than one SDR grade. The heat absorption of a DR11 and a DR7.3 are substantially different and may cause inconsistencies in the performance of the fused joint.

In the waterworks marketplace, most HDPE fittings are not made by the same manufacturer as the pipe. Most fittings are produced by fabrication shops and independent distributors. This is of significant concern. Different HDPE pipe and fitting manufacturers utilize resins from different sources. Each manufacturer's very specific and unique heat fusion procedures are based on their resin. The parameters and requirements of these procedures reflect the differences in the behavior and composition of the resins utilized by each different manufacturer. Even if the cell class is the same, resins from different resources may exhibit different performance properties. Independent fittings manufacturers may not adhere to the specific recommended procedures of the pipe manufacturer. Also, many fitting items are machined from billet and sheet stock materials from still other resin resources. Joining of these different materials together (fittings to pipe or pipe to pipe) which have different heat fusion procedures could jeopardize the joint. Consequently, the party responsible for the quality of the piping system, may find that it has been clouded and obscured.

Tracer Wires

Because it is a non-metallic substance, buried HDPE pipe cannot be located using metal detectors. Thus, tracer wires must be placed in the trench so the pipe can be located with electronic metal detection devices. Because Ductile Iron Pipe is metallic, it requires no tracer wires for location and detection.

Nearby Excavation

Existing HDPE is substantially more vulnerable than is Ductile Iron Pipe to puncture or damage during excavation and construction of nearby utilities.

Buoyancy

HDPE pipe is buoyant — a concern when installing the pipe material in areas having a high water table or when trench flooding is likely to occur. To prevent loss of completed pipe embedment through flotation of HDPE pipe, it must be anchored. Flotation is generally not a concern with normal installations of Ductile Iron Pipe.

Sun Exposure

Special precautions must be taken when HDPE pipe is exposed to sunlight for an extended period of time because, when subjected to long-term exposure to ultraviolet (UV) radiation from sunlight, HDPE pipe can suffer surface damage. This effect is commonly termed ultraviolet (UV) degradation. According to the ASTM specification, if plastic pipe is stored outdoors, it may require protection from weathering in accordance with manufacturers' recommendations. And in warm climates, the covering should allow air circulation in and around the pipe.[28] Ductile Iron Pipe is not vulnerable to the effects of exposure to sunlight or weathering.

Effects Of Scratches

Compared to Ductile Iron Pipe, HDPE is a very soft material and is consequently much more vulnerable to abrasions, scratches, and other damage during shipping and installation. In fact, ANSI/AWWA C906 states that "the walls shall be free from cuts, cracks, holes, blisters, voids, foreign inclusions, or other defects that are visible to the naked eye and that may affect the wall integrity." This is an arguably impractical stipulation relative to many rugged construction sites. Also, the AWWA Committee Report "Design and Installation of Polyethylene (PE) Pipe Made in accordance with AWWA C906"[29] states that "gouges deeper than 10 percent of the pipe wall thickness should not be placed in service. Damage of this magnitude should be corrected by removing the affected portion of pipe and subsequently rejoining the remaining pipe ends by an approved joining method." Because of Ductile Iron's great strength and durability, however, there is no measurable loss of strength due to scratches and gouges from normal handling.

Performance History

Man's ability to cast pipe probably developed from, or coincidentally with, the manufacture of cannons, which is reported as early as the year 1313. There is an official recording of Cast Iron pipe manufactured at Siegerland, Germany, in 1455 for installation at the Dillenburg Castle.

The earliest record of an AWWA standard for Gray Cast Iron pipe is contained in the Report of Proceedings of the Tenth Annual Meeting of the American Water Works Association (1890). On September 10, 1902, the New England Water Works Association adopted a more detailed standard titled "Standard Specifications for Cast Iron Pipe and Special Castings."

The advent of Ductile Iron Pipe in 1948 was one of the most significant developments in the pressure pipe industry. The first editions of ANSI/AWWA C150/A21.50 (the design standard for Ductile Iron Pipe) and ANSI/AWWA C151/A21.51 (the manufacturing standard for Ductile Iron Pipe) were issued in 1965.

The performance of Ductile Iron Pipe extends over 40 years, and because of its close physical resemblance to Gray Cast Iron pipe, the long-term record of Cast Iron can be used to predict the life of a Ductile Iron Pipeline.[30] This comparison has been enhanced by extensive research on the comparative corrosion rates between Ductile Iron and Gray Cast Iron, which has shown Ductile Iron to be at least as corrosion-resistant as Gray Cast Iron.[31]

Gray and Ductile Iron Pipe have withstood the test of time. On the other hand, ANSI/AWWA C906 was the first AWWA standard for HDPE pipe and was only first issued in 1990.

Conclusion

Ductile Iron Pipe has long been recognized as the superior pipe material for water and wastewater applications. Its tremendous strength and durability allow it to be designed under conservative assumptions and installed with confidence that the actual service conditions it experiences will not compromise its ability to perform.

Regardless of the criteria — strength, durability, tapping, flow capacity, safety factor, or actual field experience — it is easy to understand what those who know pipe have long known. Ductile Iron Pipe is the right decision!

1. ANSI/AWWA C150/A21.50 American National Standard for the Thickness Design of Ductile Iron Pipe, American Water Works Association, Denver, Colorado (1996).
2. ANSI/AWWA C906 American National Standard for Polyethylene (PE) Pressure Pipe and Fittings, 4 In. Through 63 In., For Water Distribution, American Water Works Association, Denver, Colorado (1999).
3. Original tests were conducted by Structural Composites, Inc., an independent engineering testing firm, in 1999 in Melbourne, Florida, and American Cast Iron Pipe Company in Birmingham, Alabama, in 1999 and witnessed by Professional Services Industries, an independent consulting third-party witnessing/testing firm. Supplemental tests were conducted by Plastics Engineering Laboratory, an independent testing firm, in 2000 in Lawrenceville, Georgia, and United States Pipe and Foundry Company in 1999-2000 in Birmingham, Alabama.
4. ANSI/AWWA C151/A21.51 American National Standard for Ductile-Iron Pipe, Centrifugally Cast, For Water, American Water Works Association, Denver, Colorado (1996).
5. ASTM E8 Test Methods For Tension Testing of Metallic Materials.
6. ASTM D2290 Apparent Tensile Strength of Ring or Tubular Plastics and Reinforced Plastics by Split Disk Method.
7. ASTM D638 Tensile Properties of Plastics.
8. Engineering Properties of Polyethylene, Plastic Pipe Institute, p. 3-13.
9. Engineering Properties of Polyethylene, Plastic Pipe Institute, p. 3-36.
10. Plexco/Spirolite Engineering Manual, Volume 2: System Design, p. 3.
11. Engineering Properties of Polyethylene, Plastic Pipe Institute, p. 3-36.
12. ASTM D1599 "Test Method for Short-Time Hydraulic Failure Pressure of Plastic Pipe, Tubing, and Fittings."
13. Engineering Properties of Polyethylene, Plastic Pipe Institute, p. 3-19.
14. ASTM D2837 "Standard Test Method for Obtaining Hydrostatic Design Basis for Thermoplastic Pipe Materials."
15. ANSI/AWWA C906.
16. Engineering Properties of Polyethylene, Plastic Pipe Institute, p. 3-20.
17. Design and Engineering Guide, Poly Pipe Industries, Inc., p. G1.
18. Engineering Properties of Polyethylene, Plastic Pipe Institute, p. 3-11.
19. Engineering Properties of Polyethylene, Plastic Pipe Institute, p. 3-15.
20. ASTM E23 "Notched Bar Impact Testing of Metallic Materials."
21. Polyethylene Joining Procedures, Plastic Pipe Institute, p. 6-6.
22. "Hydraulic Analysis of Ductile Iron Pipe," Ductile Iron Pipe Research Association, Birmingham, Alabama, 2000.
23. D. Jenkins. "Permeation of Plastic Pipes by Organic Chemicals," Journal AWWA, August 1991.
24. ASTM D2774 Standard Practice for Underground Installation of Thermoplastic Pressure Piping.
25. ASTM D2774.
26. AWWA C600, p. 13-14.
27. Ductile Iron Pipe Subaqueous Crossings, Ductile Iron Pipe Research Association, Birmingham, Alabama.
28. ASTM D2774.
29. AWWA Committee Report "Design and Installation of Polyethylene (PE) Pipe Made in Accordance With AWWA C906," American Water Works Association, Denver, Colorado (1998).
30. Approximately 550 U.S. and Canadian utilities are members of the Cast Iron Pipe Century Club for having Cast Iron pipe in continuous service for 100 years or more. At least 15 utilities have gained membership in the Cast Iron Pipe Sesquicentury Club for having Cast Iron pipe in continuous service for 150 years or more.
31. E.C. Sears. "Comparison of the Soil Corrosion Resistance of Ductile Iron Pipe and Gray

For more information contact DIPRA or any of its member companies.

Ductile Iron Pipe Research Association

An association of quality producers dedicated to the highest pipe standards through a program of continuing research and service to water and wastewater professionals.

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