APPENDIX A

Bending Strain using Simplified Method

INPUT

Pipe Properties:

Nominal diameter		D_i	= 42 in
Profile height..		ph	= 2.925 in
Depth from outside surface to centroid........................		c_{out}	= 1.91 in
Outside diameter........................	$D_o = D_i + 2$ ph	D_o	= 47.85 in
Diameter to centroid........................	$D = 0.5^* c_{out}$	D	= 22.02 in
Effective area..		A	= 0.41 in^2/in
Moment of inertia..		I	= 0.45 in^4/in
Pipe long-term modulus of elasticity........................		E	= 20000 psi

SELECT TARGET DEFLECTION AT GIVEN DEPTH OF FILL

Example use 5% Deflection at 1.5 ft

CALCULATE HOOP STRAIN AT GIVEN DEPTH

Height of fill over pipe..		H	= 1.5 ft
Density of soil backfill		γ_{soil}	= 120 pcf
Soil prism load........................	$W_{sp} = \gamma_{soil} D_o (H + 0.11 D_o)$	W_{SP}	= 77.3 lbf/in

Calculate vertical arching factor

Resistance factor to account for reduced soil stiffness.......		ϕ	= 0.9
Constrained soil modulus (AASHTO LRFD Table 12.12.3.4-1 (assume Sn95 soil))		M_s	= 2090 psi
Radius to centroid	$R = \left(\frac{D_o}{2}\right) - c_{out}$	R	= 22.015 in
Hoop stiffness factor..... AASHTO LRFD Eq. 12.12.3.4-4	$S_H = \frac{\phi_S M_S R}{EA}$	S_H	= 5.05
Vertical arching factor.. AASHTO LRFD Eq. 12.12.3.4-3	$VAF = 0.76 - 0.71\left(\frac{S_H - 1.17}{S_H + 2.92}\right)$	VAF	= 0.41

Calculate minimum hoop thrust compression strain

1. multiply maximum thrust by 0.4 to determine minimum thrust
2. multiply area by 0.9 to account for reduction of effective area due to local buckling. Note that for actual calculations, the AASHTO procedures for evaluating local buckling should be used to determine the area reduction.

$$\varepsilon_T = 0.4 * 0.5 * W_{SP}\left(\frac{VAF}{E(0.9A)}\right)$$

ε_T = 0.09%

CALCULATE BENDING STRAIN BASED ON TARGET DEFLECTION AND COMPUTED HOOP STRAIN

Total deflection = bending deflection + hoop thrust compression strain

Total deflection = target deflection .... ΔT_{pctg} = 5%

Assumed shape factor for bending strain for haunched pipe............. D_f = 4.0

Bending deflection .... $\Delta_{b.pctg} = \Delta_{T.pctg} - \varepsilon_T$ $\Delta_{b.pctg}$ = 4.91%

Assymmetric centroid - check maxium tension strain at outer fiber; c c = c_{out}

Bending strain..................... AASHTO LRFD Eq. 12.12.3.5.4.6-1 $\varepsilon_B = D_f \Delta_{b*pctg}\left(\frac{c}{R}\right)$ ε_B = 1.71%

CALCULATE TOTAL MAXIMUM TENSION STRAIN IN SECTION

$\varepsilon_{Total} = \varepsilon_B - \varepsilon_T$ ε_{Total} = 1.62%

APPENDIX B

Specifications for Design

This Appendix presents modifications to the AASHTO LRFD design specifications necessary to evaluate the limiting tensile stress in thermoplastic pipe.

SPECIFICATIONS

12.4.1.3 ENVELOPE BACKFILL SOILS (modify existing section)

For thermoplastic pipes A-1, A-2-4, A-2-5, or A-3

For A-1 and A-3 soils, a maximum of 50% of the particle sizes may pass the 0.150 mm (No. 100) sieve and a maximum of 20% may pass the 0.075 mm (No. 200) sieve. If these limits are not met, treat the backfill as and A-2-4 or A-2-5 material.

12.12.3.31 CHEMICAL AND MECHANICAL REQUIREMENTS (add to Existing Section)

Add the following properties:

Corrugated PE Pipe, AASHTO M 294 shall have the following minimum properties at 100 years:

$F_{utension}$ = 500 psi

E = 20,000 psi

where:

$F_{utension}$ = minimum tensile strength at 100 years.

E_{100} = modulus of elasticity at 100 years.

Performance in compression shall be evaluated using the 50 year properties currently in Table 1.

12.12.3.4.1 MINIMUM THRUST (New Section)

Compute the minimum thrust in the pipe wall as:

$$T_{Lmin} = P_F K_T (D_o/2) \quad (12.12.3.4.1\text{-}1)$$

where:

COMMENTARY

C12.4.1.3

A-2-4 and A-2-5 materials require somewhat more care in placing under the haunches, in controlling moisture content and in compacting.

The limitation on A-1 and A-3 soils are set to avoid the use of uniform fine sands. If such materials are used, they are sensitive to moisture content and should be as silty soils.

C12.12.3.31

Minimum properties for 100 year service life are considered temporary until additional testing is completed to determine actual values.

Compression capacity is based on strain. NCHRP Report 438 *LRFD Specifications for Plastic Pipe and Culverts* concluded that the compression strain limit is not time dependent, thus the 50 year limit is applicable to 100 year design.

C12.12.3.4.1

The LRFD specifications have historically focused on calculating the maximum compressive thrust in the pipe wall. Since thermoplastic pipe may crack if subjected to excess tension stress, the

K_T = 0.4 for minimum thrust used in calculating maximum tension force in pipe

In calculating P_F for use in Equation 1, water load and live load shall be neglected.

12.12.3.5.4a General (Modify Existing Section)

Replace Eq. 3 with:

$$\varepsilon_{tu} = \varepsilon_{bu} - \frac{T_{L\,min}}{A_{eff} \quad E_{100}} \text{ x } \frac{\gamma B}{\gamma E} \leq \varepsilon_{tt}$$

(12.12.3.5.4a-3)

redefine ε_{tt} as:

ε_{tt} = factored long term tensile strain

= $F_{utension}/E_{100}$

In Eq. 3 replace the term T_L with the term T_{LMin} as computed in 12.12.3.4.1, and replace the term E_{50} with the term E_{100}.

minimum thrust stress is required. The maximum tension stress is computed as the maximum tension stress due to bending minus the minimum compression thrust stress.

APPENDIX C

Specifications for Installation

This Appendix supplements AASHTO LRFD Construction Specifications, Chapter 30 for Thermoplastic Pipe to meet the requirements of the Florida DOT design specifications for 100 year service life.

SPECIFICATIONS

30.3.2 Bedding Material and Structural Backfill (Add to existing aection)

For A-1 and A-3 soils, a maximum of 50% of the particle sizes may pass the 0.150 mm (No. 100) sieve and a maximum of 20% may pass the 0.075 mm (No. 200) sieve. If these limits are not met, treat the backfill as and A-2-4 or A-2-5 material.

30.5.2 Trench Widths (Add to existing section)

If the trench walls do not stand without support, then increase the trench width to provide a minimum of 1/2 pipe diameter of structural backfill on either side of the pipe.

Trench width must be sufficient to allow compaction of backfill at the springline elevation without damaging pipe.

When supports such as trench boxes are used, ensure that support of the pipe and its embedment are maintained throughout the installation. Ensure that sheeting is sufficiently tight to prevent washing out of native soil from behind the trench box.

Do not disturb the installed pipe and its embedment when moving trench boxes. Trench boxes should not be used below the top of the pipe zone unless methods approved in advance are used for maintaining the integrity of the embedment material. As supports are moved, any voids left by the trench walls below the top of the pipe zone must be filled with specified structural backfill, compacted per these specifications.

COMMENTARY

C30.3.2

A-1 and A-3 soils not meeting these criteria are uniform fines sands and should be handled like A-2-4 and A-2-5 backfill materials.

C30.5.2

Flexible pipe require soil support at the sides, and unstable trench walls are an indication that a wider trench width is required. This criterion does not refer to trenches for which trench supports are required only for worker safety.

30.5.4 Structural Backfill (Modifiy existing section)

Change 1st sentence of second paragraph to:

A minimum compaction level of 95 percent standard density per AASHTO T 99 shall be achieved. In addition to other requirements, backfill must be compacted at least at the springline level of all pipe with diameter greater than 12 in.

A higher density is required to increase assurance that the structural backfill will be stable for the 100 year design life.

30.5.5 Minimum Cover (modify existing section)

Minimum depth of cover for corrugated polyethylene pipe shall be as required in Table 3.5.5-1a

C30.5.5

Table 3.5.5-1a –Depth of Cover (in.)

Pipe Diameter	Rigid Pavement Depth below bottom of pavement, in.	Flexible Pavement Depth below bottom of base, in.	No Pavement	
			Commercial	Non-Commercial
up to 48 in.	9	15	24	12
54 in., 60 in	15	21	30	24

APPENDIX D

Florida Method of Test for Determining Slow Crack Growth Resistance of Corrugated HDPE Pipes

Designation, FM 5-572

Florida Method of Test for Determining Slow Crack Growth Resistance of Corrugated HDPE Pipes

Designation, FM 5-572

1. SCOPE

1.1 This test method is used to evaluate the slow crack growth resistance of the HDPE corrugated pipe under a constant ligament stress (CLS) in an accelerating environment, which is either 10% Igepal or water at elevated temperatures.

1.1 The test consists of three procedures to assess the pipe liner, corrugation/liner junction and longitudinal profiles of the corrugated pipes.

1.2 This test method measures the failure time associated with a given test specimen at a constant, specified, ligament stress level.

1.3 The values stated in inch-pound units are to be regarded as the standard. The values given in parenthesis are mathematical conversions to SI units, which are provided for information only and are not considered standard.

2. REFERENCED DOCUMENTS

2.1 ASTM Standards:

D 638 Tensile Properties of Plastics

D 1600 Terminology for Abbreviated Terms Relating to Plastics

D5397 Test Method for Evaluation of Stress Crack Resistance of Polyolefin Geomembranes

Using Notched Constant Tensile Load Test

F 1473 Test Method for Notch Tensile Test to Measure the Resistance to Slow Crack Growth of Polyethylene Pipes and Resins

F 2136 Standard Test Method for Notched Constant Ligament Stress (NCLS) Test to Determine Slow Crack Growth Resistance of HDPE Resins or HDPE Corrugated Pipe

2.2 Other Documents:

AASHTO (American Association of State Highway and Transportation Officials) Standard Specification M 294.

3. TEST METHOD

3.1 This test method subjects a dumbbell-shaped, notched or un-notched test-specimen to a constant ligament stress in the presence of either a surface-active agent or water at an elevated temperature.

4. APPARATUS

4.1 Blanking Die. - A die suitable for cutting test specimens with holes to the dimensions and tolerances specified in Figures 1 and 2. Figure 1 shows the dimensions of the die that have the same geometry used for ASTM F 2136, which shall be used for specimen thickness from 0.040 to 0.125 inch. Figure 2 shows the dimensions of the die that have the same geometry used for ASTM D 638 type IV, which shall be used for specimen thickness from 0.126 to 0.25 inch.

4.2 Stress Crack Testing Apparatus. - A lever loading machine, with a lever arm ratio of 3:1, 4:1 or 5:1 similar to that described in ASTM D 5397. Alternatively, the tensile load may be applied directly using dead weights or any other method for producing a constant load. The bath solution temperature shall be set at the desired test temperature to an accuracy of (+/- 1 ^{o}C)

(Testing apparatus is available from BT Technology, Inc. 320 N. Railroad Street, Rushville, IL 62681, Materials Performance, Inc. 2151 Harvey Mitchell Pkwy, S. Suite 208, College Station, TX 77840, Satec Systems, 900 Liberty Street, Grove City, PA 16127, or equivalent.)

4.3 Notching Device. - Notch depth is an important variable that must be controlled. Section 5.2 describes the notching procedure and type of apparatus used. The approximate thickness of blade should be 0.008 – 0.012 in (0.2 to 0.3 mm).

Note 1: A round robin was conducted to determine the effect of types of blades on the notch depth. In this study several types of steel blades (single edge, double edge etc.) from various manufacturers were used by the round robin participants. The round robin consisted of seven laboratories using 2 types of resins molded into plaques. The standard deviation of the test results within laboratories is less than +/-10 %.

(Notching apparatus is available from BT Technology, Inc. 320 N. Railroad Street, Rushville, IL 62681, Satec Systems, 900 Liberty Street, Grove City, PA 16127, or equivalent.)

4.4 Micrometer (or caliper) capable of measuring to +/- 0.0005 in (+/- 0.0127 mm).

4.5 Electronic scale for measuring shot weight tubes capable of measuring to +/- 0.0002 lbs. (0.1 g).

4.6 Timing device capable of recording failure time to the nearest 0.1 h.

5. PROCEDURE A – PIPE LINER TEST

6.1 Specimen Preparation:

6.1.1 Test specimens are to be die cut from the inner liner of the corrugated pipe. The specimens shall be oriented along the longitudinal axis of the pipe, as shown in Figure 3.

6.1.2 The die cut shall start from the inner liner surface (i.e., the inner liner surface shall face up towards the die).

Note 2: Select the appropriate die (either ASTM F 2136 or ASTM D 638 Type IV) for the test (see Section 4.1)

6.1.3 Five specimens shall be taken from the test pipe. Specimen shall be cut from the same circumferential section of the test pipe at five locations of 70^{o} apart from each other, as shown in Figure 4

6.1.4 The average thickness of each test specimen shall be determined by averaging three thickness measurements of the constant neck section.

5.2 Notching

5.2.1 Specimens shall be notched across the center of the constant neck section on the **OUTER** liner surface, as shown in Figure 5. The notch shall be cut at a maximum rate of 0.2 inch per minute (5.0 mm per minute) to a depth of (a) that is equal to 20% of the average thickness of the liner (See Section 6.1.4). Notch depth shall be controlled to +/- 0.001 in (+/- 0.025 mm) by measuring the notch depth with the aid of a microscope.

5.2.2 No single razor blade shall be used for more than 20 test specimens

5.3 Calculation of Test Load:

5.3.1 For each specimen, measure the reduced section width (W) and thickness (T), to the nearest 0.001 in using a micrometer (or caliper), and calculate the notch depth (a).

5.3.2 At each loading point, using the equation (1), determine the load (P) that must be hung on the appropriate lever arm to produce the required ligament-stress. The necessary load shall be prepared accurately enough that the ligament-stress does not vary by more than +/ - 0.5%. The appropriate applied load is:

$$P = \frac{S * W * (T - a) - C.F.}{M.A.} \quad (1)$$

Where:

P = *load to be applied to the lever arm (lbs.)*
S = *specified ligament stress (600 psi)*
W = *cross sectional width of the test specimen (in).*

T = *thickness of the test specimen (in).*
a = *the depth of the notch (in)*
$C.F.$ = *correction factor for individual lever weights, based on unit average of lever arm minus weight of sample holding rod. (lbs.).*
$M.A.$ = *mechanical advantage of the test apparatus lever.*

5.3.3 Each test weight so determined is to be labeled (or otherwise correlated to each test position) and applied to the appropriate lever arm on the test apparatus.

5.4 Reagent

5.4.1 The stress cracking reagent shall consist of 10% nonylphenoxy poly (ethyleneoxy) ethanol (Igepal CO-630 from Rhone-Poulenc or equivalent) by volume in 90% de-ionized water. Solution level is to be checked daily and de-ionized water used to keep the bath at a constant level.

5.4.2 Maintain temperature in the bath at 122 +/- 2 °F (50 ± 1°C).

5.5 Testing

5.5.1 Determine the weight to be placed on each specimen, and load the weight tubes with shot. Do not attach the shot tube to the lever arm.

5.5.2 Attach the specimens to the loading frame. Make sure that bending the specimen does not activate the notch. Lower the specimen into the bath, and condition the specimens in the bath for at least 30 minutes.

5.5.3 Reset the specimen timer to zero.

5.5.4 Check that the weight is the correct weight for the particular specimen, and carefully connect the weight tube to the appropriate lever arm for the specimen. Apply the load gradually within a period of 5 to 10 second without any impact on the specimen.

5.5.5 Start the specimen timer immediately after loading

6. TEST PROCEDURE B – CORRUGATION/LINER JUNCTION TEST

6.1. Specimen Preparation:

6.1.1 Identify the machine direction of the pipe.

6.1.2 Use reciprocating saw to make a circumferential cut to remove two corrugations from the pipe.

6.1.3 Mark five locations with 70° apart according to Figure 3.

6.1.4 Use a skill saw to make two longitudinal cuts with 5 inch apart at each of the five locations.

6.1.5 Use a band saw to remove the two corrugations from the 5 inch section. The height of the remaining corrugation on each side of the valley shall be minimum of 0.25" and maximum of 0.5". The machine direction must be clearly marked on each of the five sections.

6.1.6 The corrugation side must be placed upper so that it is facing the die.

6.1.7 The ASTM D 638 Type IV die shall be used to die cut specimens from the junction region of the pipe. The junction shall be positioned within the constant neck section of the die. If the valley width is narrower than the constant neck section of the die, both junctions can be tested simultaneonsly, as shown in Figures 6 and 7. When the length of the valley is longer than the constant neck section, each junction shall be tested separately, as shown in Figures 8 and 9. The machine direction must be identified on each of the five specimens.

Note 3: The specimen shall be removed from the die carefully to avoid imposing stress at the junction.

6.1.8 Measure the thickness of the liner section of the specimen. Three measurements shall be recorded and the lowest value shall be used in the applied load calculation.

6.2 Calculation of Test Load:

6.2.1 For each specimen, measure the reduced section width (W), and the lowest liner thickness (T).

6.2.2 At each loading point, using the equation (2), determine the load (P) that must be hung on the appropriate lever arm to produce the required ligament-stress. The necessary load shall be prepared accurately enough that the ligament-stress does not vary by more than +/ - 0.5%. The appropriate applied load is:

$$P = \frac{S * W * T - C.F.}{M.A.} \qquad (2)$$

Where:

P = *load to be applied to the lever arm (lbs.)*

S = *Applied stress (see specification table)*

W = *cross sectional width of the test specimen (in).*

T = *minimum thickness of the test specimen (in).*

$C.F.$ = *correction factor for individual lever weights, based on unit average of lever arm minus weight of sample holding rod. (lbs.).*

$M.A.$ = *mechanical advantage of the test apparatus lever.*

6.2.3 Each test weight so determined is to be labeled (or otherwise correlated to each test position) and applied to the appropriate lever arm on the test apparatus.

6.3 Reagent

6.3.1 The stress cracking reagent shall be de-ionized water. The water level is to be checked daily and de-ionized water used to keep the bath at a constant level.

6.3.2 Maintain temperature in the bath at +/- 2 °F (± 1°C) of the set temperature.

6.4 Testing

6.4.1 Determine the weight to be placed on each specimen, and load the weight tubes with shot. Do not attach the shot tube to the lever arm.

6.4.2 Attach the specimens to the loading frame. Lower the specimen into the bath, and condition the specimens in the bath for at least 30 minutes.

6.4.3 Reset the specimen timer to zero

6.4.4 Check that the weight is the correct weight for the particular specimen, and carefully connect the weight tube to the appropriate lever arm for the specimen. Apply the load gradually within a period of 5 to 10 second without any impact on the specimen.

6.4.5 Start the specimen timer immediately after loading.

6.4.6 Record the time to failure of each specimen to the nearest 0.1 h.

7 PROCEDURE C – LONGITUDINAL PROFILE TEST

7.1 Definition of longitudinal profile - Longitudinal profile(s) includes features that run along the longitudinal axis of the pipe in either continuously or repeating in regular intervals. These features may be a part of the pipe design (for example vent holes or mold line) or those generated by extrusion defects.

7.2 Speciment perparation

8.2.1 The ASTM D 638 Type IV die shall be used to die cut specimens from the profile region of the pipe. The orientation of the specimen shall align with the circumference of the pipe. The profile feature shall be positioned at the center position of the constant neck section of the die.

8.2.2 For the vent-hole profile, the vent-hole shall be positioned at the center of the specimen. The crown-portion of the vent hole shall be removed, as shown in Figure 10.

8.2.3 For each profile, five specimens shall be cut from the test pipe at locations of 4 corrugations apart from each other.

8.2.4 For vent-hole specimens, measure the thickness of the liner portion (T_L) of the vent hole. Two measurements shall be recorded and the lowest value shall be used in the applied load calculation.

8.2.5 For other longitudinal profiles, such as mold line, the thickness of the constant neck section of the specimen shall be measured. Three measurements shall be recorded and the lowest value shall be used fin the applied load calculation

8.2 Calculation of Test Load:

8.3.1 For each specimen, measure the reduced section width (W), and the lowest thickness for the specimen (T) or liner portion (T_L).

8.3.2 At each loading point, using the equation (3) or (4), determine the load (P) that must be hung on the appropriate lever arm to produce the required ligament-stress. Equation (3) is applied to vent-hole profile only; all other longitudinal profiles shall use Equation (4) to calculate the load. The necessary load shall be prepared accurately enough that the ligament-stress does not vary by more than +/ - 0.5%. The appropriate applied load is:

$$P = \left(\frac{(S - BS) * W * T_L - C.F.}{M.A.} \right) \quad (3)$$

$$P = \left(\frac{(S - BS) * W * T - C.F.}{M.A.} \right) \quad (4)$$

Where:

P = *load to be applied to the lever arm (lbs.)*
S = *specified stress (see specification table)*
W = *cross sectional width of the test specimen (in).*
T = *minimum thickness of the test specimen (in).*
T_L = *minimum thickness of the liner (in).*
$C.F.$ = *correction factor for individual lever weights, based on unit average of lever arm minus weight of sample holding rod. (lbs.).*
$M.A.$ = *mechanical advantage of the test apparatus lever.*
BS = *bending stress which varies with the profile of the pipe:*

$$BS = \left(\frac{(T_L)/2}{R} \right) * (E) \quad \text{for vent hole test}$$

$$BS = \left(\frac{(T)/2}{R} \right) * (E) \quad \text{for other longitudinal profiles}$$

where: R = *Inside radius of the pipe*
E = *long term modulus (20,000 psi)*

7.3.3 Each test weight so determined is to be labeled (or otherwise correlated to each test position) and applied to the appropriate lever arm on the test apparatus.

7.4 Reagent

7.4.1 The stress cracking reagent shall be de-ionized water. The water level is to be checked daily and de-ionized water used to keep the bath at a constant level.

7.4.2 Maintain temperature in the bath at +/- 2 °F (± 1°C) of the set temperature.

7.5 Testing

7.4.1 Determine the weight to be placed on each specimen, and load the weight tubes with shot. Do not attach the shot tube to the lever arm.

7.4.2 Attach the specimens to the loading frame. Lower the specimen into the bath, and condition the specimens in the bath for at least 30 minutes.

7.4.3 Reset the specimen timer to zero

7.4.4 Check that the weight is the correct weight for the particular specimen, and carefully connect the weight tube to the appropriate lever arm for the specimen. Apply the load gradually within a period of 5 to 10 second without any impact on the specimen.

7.4.5 Start the specimen timer immediately after loading

7.4.6 Record the time to failure of each specimen to the nearest 0.1 h.

8. REPORTING RESULTS

Test report shall include the following information:

10.1 All details necessary for complete identification of the material tested (density, melt index, lot number, etc.).

10.2 Test information shall be recorded according to Table 1 for test Procedure A and Table 2 for test Procedures B and C.

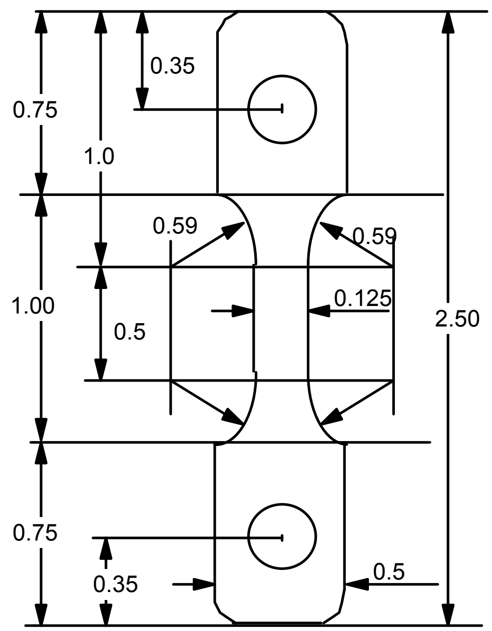
10.3 Report the failure time for each of the five specimens and the arithmetic average of the five specimens.

Table 1 – Recommend Data Record Template for Test Procedure A

Date: Sample Identification: Pipe Region being Evaluated: Test Procedure: Test Temperature: Solution:						
Applied Stress (σ) (psi)	Average Thickness (T) (in)	Notch Depth (a) (in)	Ligament Thickness (T-a) (in)	Specimen Width (W) (in)	Applied Load (P) (lb)	Failure Time (t) (hr)

Table 2 – Recommend Data Record Template for Test Procedures B and C

Date: Sample Identification: Pipe Region being Evaluated: Test Procedure: Test Temperature: Solution:				
Applied Stress (σ) (psi)	Minimum Thickness (T) or (T_L) (in)	Specimen Width (W) (in)	Applied Load (P) (lb)	Failure Time (t) (hr)



Note - Dimensions in inches to an accuracy of 0.005 inches

Figure 1. Specimen Geometry –Die Type I Dimensions

Note 4:. The test specimen is intended to have the same geometry used for ASTM D 5397 specimens. The length of the specimen can be changed to suit the design of the test apparatus. However, there should be a constant neck section with length at least 0.5 in (13 mm) long.

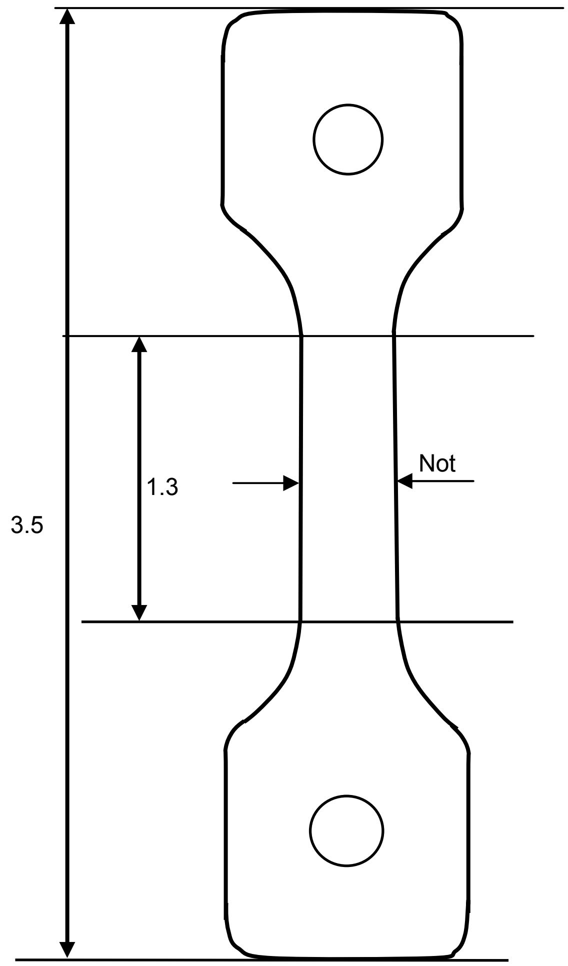


Figure 2. Specimen Geometry –Die Type II Dimensions

Note 5:. The test specimen is intended to have the same geometry used for ASTM D 638 Type IV specimens. The length of the specimen can be changed to suit the design of the test apparatus. However, there should be a constant neck section with length at least 1.3 in long.

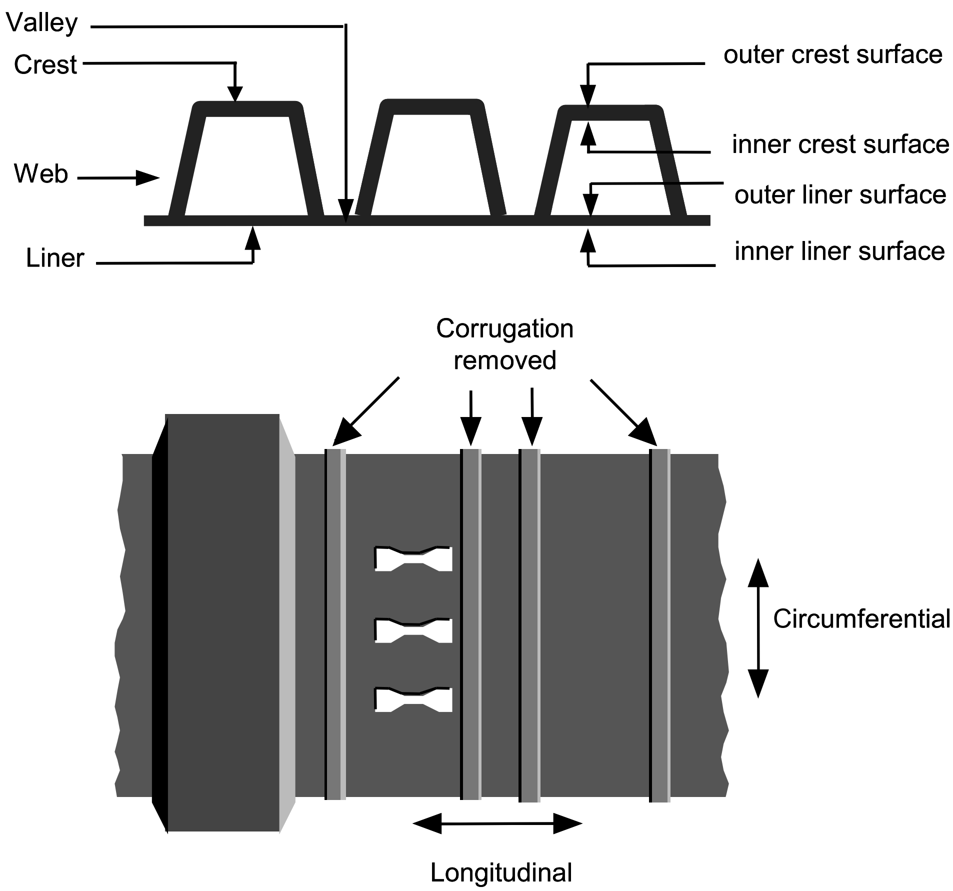
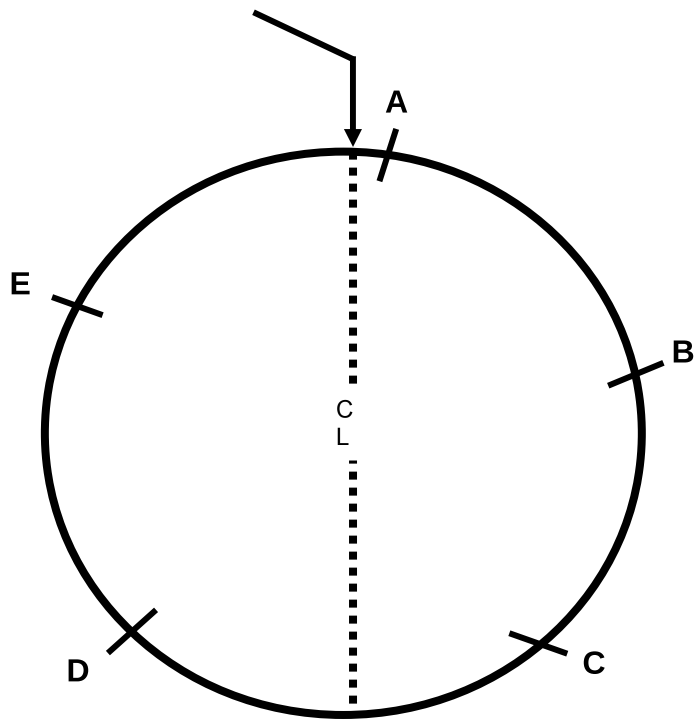
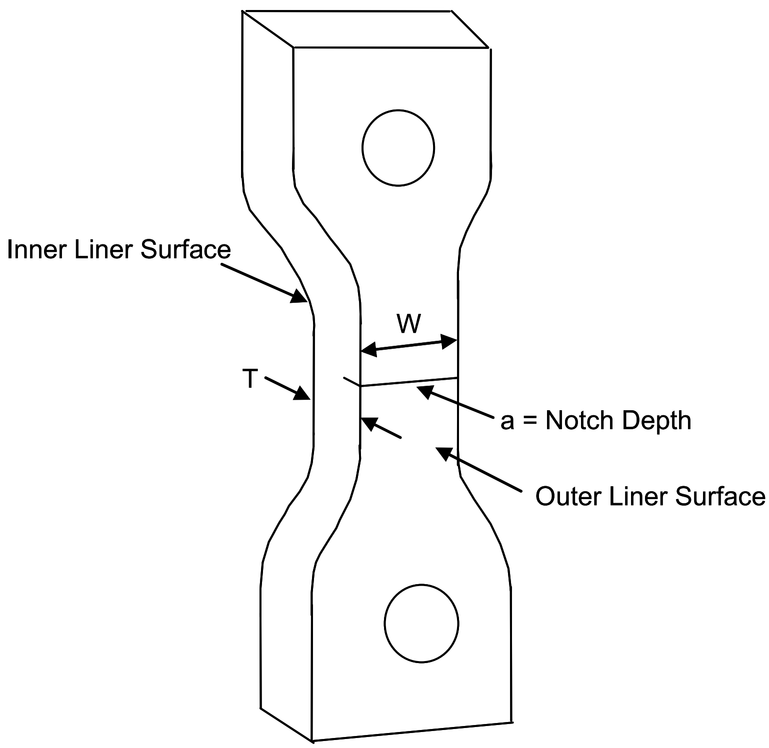


Figure 3 – Location of test specimens taken from the liner part of the pipe

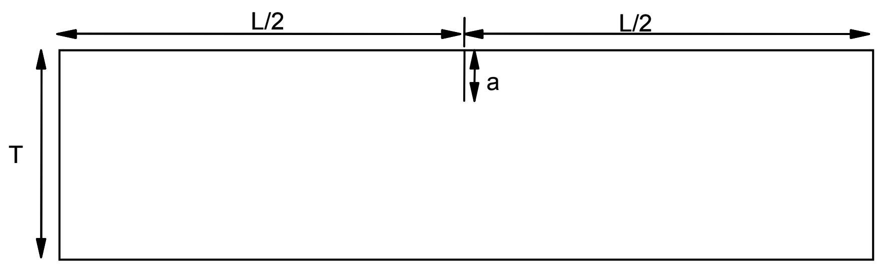


A, B, C, D and E shall be 70^{o} apart

Figure 4 – Location of the five test specimens around the pipe



Front view of the notched specimen



Side view of the notched specimen

T = Thickness
W = Specimen width

Figure 5 – Notch position with respect to the geometry of the specimen

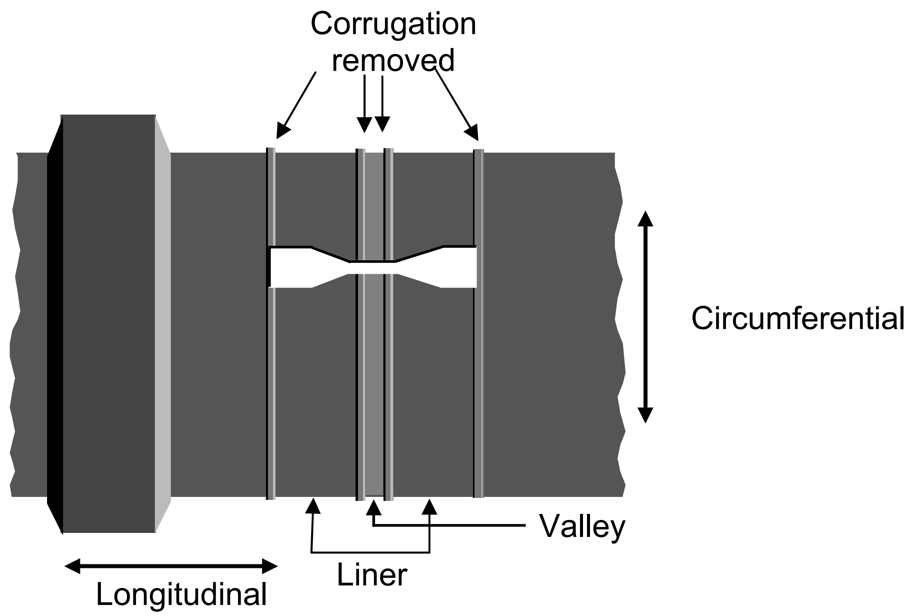


Figure 6 – Location of the test specimen when the width of valley is narrower than the constant neck section of the die.

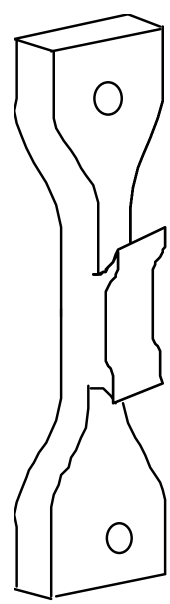


Figure 7 – A schematic diagram of the test specimen from Figure 6.

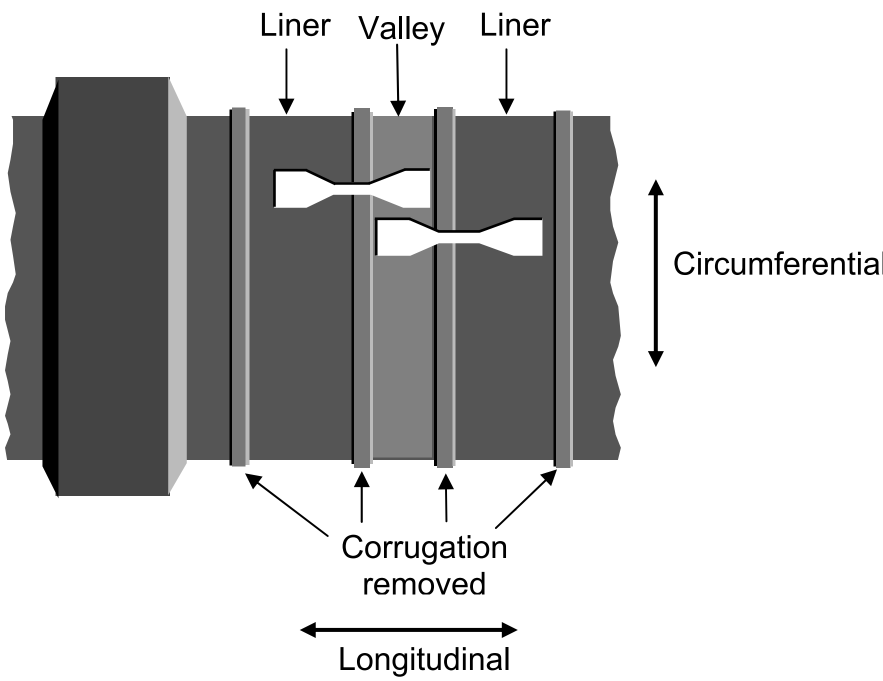


Figure 8 – Locations of the specimen taken from each side of the junction

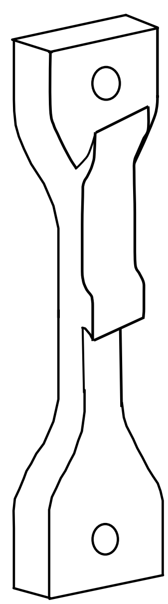


Figure 9 – A schematic diagram of the test specimen from Figure 8

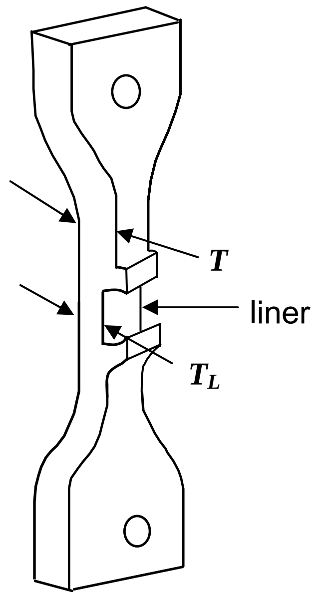


Figure 10 – A side-view of a vent hole test specimen with crown part being removed

APPENDIX E

Florida Method of Test
for Predicting the Crack Free Service Life
of HDPE Corrugated Pipes

Designation, FM 5-573

Florida Method of Test for Predicting the Crack Free Service Life of HDPE Corrugated Pipes

Designation, FM 5-573

3.1 SCOPE

1.1 This test method is used to predict the crack free service life of high-density polyethylene (HDPE) corrugated pipes in view of Florida DOT 100-year design service life requirement.

1.2 This test utilizes data obtained from test method that was designed to evaluate the stress crack resistance (SCR) of corrugate pipes. The SCR test methods for junction and longitudinal profiles of the pipe are described in FM 5-572, Procedures B and C, respectively.

1.3 The SCR test for junction and longitudinal profiles shall be performed at minimum of two elevated temperatures and two stress levels in the incubation environment of water.

1.4 The SCR test data obtained from the elevated temperatures are shifted to a lower site specific temperature using the rate process method equation, as shown in Eq. (1).

$$\log t = A + \frac{B}{T} + \frac{C \log S}{T} \qquad (1)$$

where:

t	=	time, hr
T	=	Absolute temperature, K (K = ^{o}C + 273)
S	=	Applied stress, psi, and
A,B,C	=	constants

2. REFERENCED DOCUMENTS

2.1 ASTM Standards:

D1600 Terminology for Abbreviated Terms Relating to Plastics

D2837 Standard Test Method for Obtaining Hydrostatic Design Basis for Thermoplastic Pipe Materials or Pressure Design Basis for Thermoplastic Pipe Products

2.2 FDOT Documents:

FM 5-572 Test Method for Determining Slow Crack Growth Resistance of HDPE Corrugated Pipes.

3. STRESS CRACK RESISTANCE (SCR) TEST

3.1 The SCR test shall be performed according to FM 5-572.

3.1.1 Procedure B uses pipe junction specimens

3.1.2 Procedure C uses specimens consist of longitudinal profiles, such as vent-hole and mold line

3.2 The applied stresses at different test temperatures are shown in Table 1.

Note 1 – Tests performed at stresses higher than the defined values may enter into the transition region of the ductile-brittle curve thereby yielding a longer failure time than that of the lower stress. Details of the ductile-brittle transition can be found in ASTM D5397.

3.3 Five specimens are tested at each stress level.

Table 1 – Applied Stresses at Different Test Temperatures

Test Temperature (^{o}C)	Applied Stresses (psi)
70	650
80	650, 450

4. PREDICTION PROCEDURE

4.1 The average temperature of 23^{o}C shall be used as the general site temperature in lifetime extrapolation analysis

4.2 To determine the brittle failure performance, solve for the three coefficients (A, B and C) of the rate process method equation, Eq. (1), using all 15 data points (5*3 = 15). A least squares multi-variable linear regression method is applied to calculate the three coefficients.

4.3 Using Eq. (1) to calculate the failure time at applied stress of 500 psi at a temperature of 23^{o}C (296 K). The failure time should be greater than 100 yr. (876,000 hr).

5. REPORTING RESULTS

Test report shall include the following information:

6.1 All details necessary for complete identification of the material tested (AASHTO M 294 cell class).

6.2 Present all of the data in both table and graphic forms. The format of the table is shown in Table 2. The graphic form shall be presented by plotting the logarithm of applied stress versus the logarithm of the failure time at each of the tested temperatures and stresses.

6.3 Report the three coefficient values, A, B and C.

6.4 Report the predicted failure time at 23^{o}C and 500psi.

Table 2 – Recommend Data Record Template

Test Temperature (^{o}C)	Applied Stress (psi)	Average Thickness (in)	Applied Load (lb)	Failure Time (hr)	Average Failure Time (hr)
80	650				
80	450				
70	650				

APPENDIX F

Florida Method of Test
for Predicting the Oxidation Resistance
of HDPE Corrugated Pipes

Designation, FM 5-574

Florida Method of Test
for Predicting the Oxidation Resistance of
HDPE Corrugated Pipes

Designation, FM 5-574

3.1.1 SCOPE

1.1 This test method is used to predict the oxidation resistance of corrugated high density polyethylene (HDPE) pipes in view of Florida DOT 100-year design service life requirement. This protocol utilizes the oxidative induction time (OIT), tensile and melt index tests to evaluate accelerated aging pipe samples.

1.2 The aging acceleration is achieved by incubating a minimum of three different elevated temperatures in the water environment.

1.3 The OIT is used to assess the remaining functional antioxidants in the aging samples.

1.4 The melt index test is used to assess changes in the molecular weight of the aging samples.

1.5 The tensile test is used to assess changes in the engineering properties of the aging samples.

1.6 The tensile and melt index tests are performed along with OIT test to monitor changes in the antioxidant and polymer structure during the course of incubation

1.7 The three sets of data obtained from the elevated temperatures are extrapolated to a lower site specific temperature using the Arrhenius equations to determine the depletion rate of antioxidants, to predict the lifetime of antioxidant package and to predict the lifetime of the pipe sample.

2. REFERENCED DOCUMENTS

2.1 ASTM Standards:

D1600 Terminology for Abbreviated Terms Relating to Plastics

D3895 Oxidative-Induction Time of Polyolefins by Differential Scanning Calorimetry

D1238 Standard Test Method for Melt Flow Rates of Thermoplastics by Extrusion Plastometer

D638 Test Method for Tensile Properties of Plastics

2.2 FDOT Documents:

FM 5-572 Test Method for Determining Slow Crack Growth Resistance of HDPE Corrugated Pipes.

3. INCUBATION PROCEDURE

3.1 Procedure A – Single Point Test

3.1.1 Incubation three junction specimens according to FM 5-572, Procedure B.

3.1.2 The temperature of the water bath shall be maintained at 85 $\pm$ 1^{o}C.

3.1.3 A tensile stress of 250 psi shall be applied to each specimen.

3.1.4 The duration of the incubation shall be 187 days.

3.1.5 The OIT value of each of the three incubated specimens shall be evaluated using test procedure according to Section 4.1.1.

3.2 Procedure B – Full Oxidation Resistance Test

3.2.1 Prepare minimum of 45 pipe samples (liner and crown) with dimensions of 5 inch in the circumferential direction and 4 inch in the longitudinal direction.

3.2.2 Place 15 samples in each of the three hot water baths.

Note 1 - Since polyethylene is lighter than water, stainless steel metal clips shall be attached to the samples to hold them down. The samples must be separated from each other during the incubation.

3.2.3 The incubation shall be at three different temperatures with a 10^{o}C interval between them. The temperatures of the three baths shall range between 65 and 85^{o}C.

Note 2 – four different temperatures will generate greater accuracy in the extrapolation.

3.2.4 In the first 6 months, incubated samples shall be removed every 2 months for evaluation; thereafter remove an incubated sample from each of the baths in every 6-month.

3.2.5 The duration of the incubation shall be different depending on the intended scope of the test.

3.2.6 For the determination of antioxidant depletion, the incubation shall be carried out until 70% decrease in the OIT value at two incubation temperatures, or other specified values.

3.2.7 For predicting the lifetime of antioxidant, the incubation shall be carried out until 90% decrease in the OIT value at all three incubation temperatures.

3.2.8 For predicting the lifetime of pipe, the incubation shall be carried out until there is 80% decrease in the tensile breaking strain at two incubation temperatures.

4. EVALUATION OF ORIGINAL AND INCUBATED SAMPLES

4.1 OIT Test

4.2.1 Perform OIT test according to ASTM D3895, employing the following procedures:

4.2.1.1 Use open aluminum pan.

4.2.1.2 A two-point temperature calibration must be performed once a week.

4.2.1.3 Two replicates shall be tested for each incubated sample.

4.2 Melt Index (MI) Test

4.1.1 Perform MI test according to the ASTM D 1238 using the test condition $190^{o}C/2.16$ kg.

4.1.2 Two replicates shall be tested for each incubated sample.

4.3 Tensile Test

4.3.1 Five ASTM D 638-TypeV test specimens shall be die cut from the original non-incubated sample and incubated samples. The length of the specimens shall be parallel to the longitudinal direction of the pipe.

4.3.2 Perform tensile tests according to ASTM D638-TypeV, using a strain rate of 2 in/min. Record yield stress, yield strain, break stress and break strain.

Note 3 – the yield strain and break strain can be obtained using cross-head movement instead of an extensometer.

5. DETERMINE ANTIOXIDANT DEPLETION RATE

5.1 To perform the analysis, the OIT value at two of the three incubation temperatures much reach greater than 60% reduction (40% retained).

5.2 Plot the average OIT retained value in ln(OIT) versus incubation time, as shown in Figure 1.

5.3 Fit the data with the exponential equation starting from 100% OIT retained.

5.4 The slope of the line is the depletion rate of the antioxidant at that test temperature.

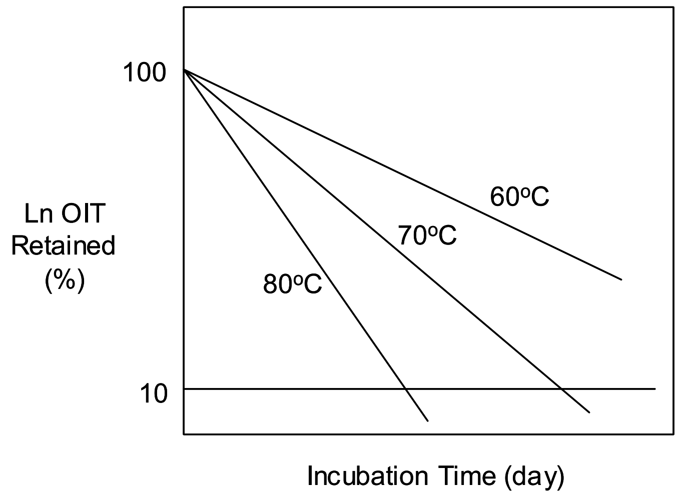


Figure 1 – Ln(OIT) versus time plot

6 ANTIOXIDANT LIFETIME PREDICTION

6.1 To perform the prediction analysis, the OIT value at two of the incubation temperatures much reach greater than 90% reduction (i.e., 10% OIT retained)

6.2 Plot the average OIT retained value in In(OIT) versus incubation time, as shown in Figure 1.

6.3 Fit the data with exponential equation starting from 100% OIT retained.

6.4 Present the slope (S) values in a table together with the incubation temperature, as shown in Table 1.

Table 1 – Antioxidant depletion rate at each incubation temperature

Slope (S)	Incubation Temperature (T) (°C)	Incubation Temperature (T) (K)	Inverts Temperature (1/T) (1/K)

6.5 Perform Arrhenius plot by plotting In(S) versus (1/T). The three data points shall be fitted with a straight line, as shown in Figure 2.

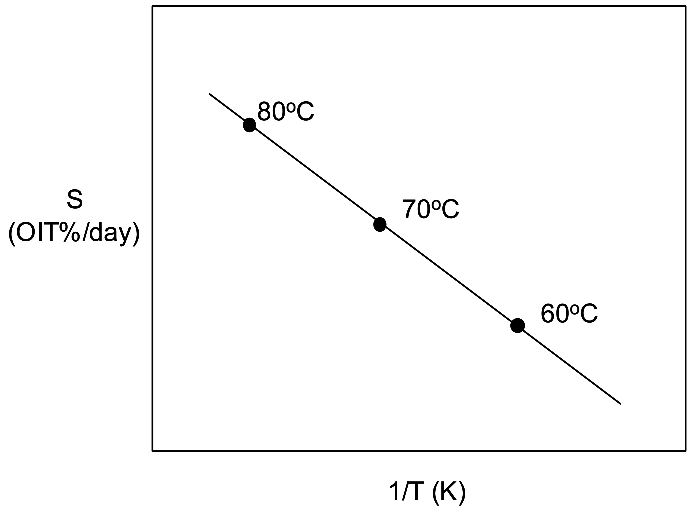


Figure 2 – Arrhenius plot of the antioxidant depletion rate versus temperature

6.6 The resulting Arrhenius equation, as shown in Equation (1), from Figure 2 shall be used to extrapolate the antioxidant depletion rate (S) at specific site temperature.

$$S = A*\exp(-E/RT) \qquad (1)$$

where:

S = OIT depletion rate
E = Activation energy of the antioxidant depletion reaction under this test condition (kJ/mol)
R = gas constant (8.314 J/mol.K)
T = test temperature in absolute temperature (K)
A = constant

6.7 The average temperature of 23°C shall be used as the general site temperature in the lifetime extrapolation analysis.

6.8 The lifetime (t) of the antioxidants at site specific temperature shall be calculated using Equation (2).

$$OIT = P* \exp(- S*t) \qquad (2)$$

where:

OIT = critical OIT time (min.)
P = original OIT of the geomembrane (min.)
S = OIT depletion rate (min/day)
t = lifetime (days)

Note 4 – The critical OIT value can be corresponding to the onset of decrease in tensile elongation, the onset of increase in MI value, the OIT value of unstabilized polyethylene pipe resin.

7. PREDICTION METHOD TO DETERMINE LIFETIME OF PIPE BASED ON OXIDATION DEGRATION

7.1 To perform this analysis, the break strain shall decrease more than 80% at all three incubation temperatures.

7.2 Calculate the average break strain at each incubation interval. Determine the percent break strain retained value using Equation (3).

$$\%\ break\ strain\ retained = \frac{average\ strain\ value\ at\ each\ incubation\ interval}{average\ strain\ value\ of\ original\ sample} \qquad (3)$$

7.3 Plot the percent break strain retained value versus incubation time for three incubation temperatures, as shown in Figure 3. From the plot, determine the time to reach 20% break strain retained (i.e., 80% drop in break strain).

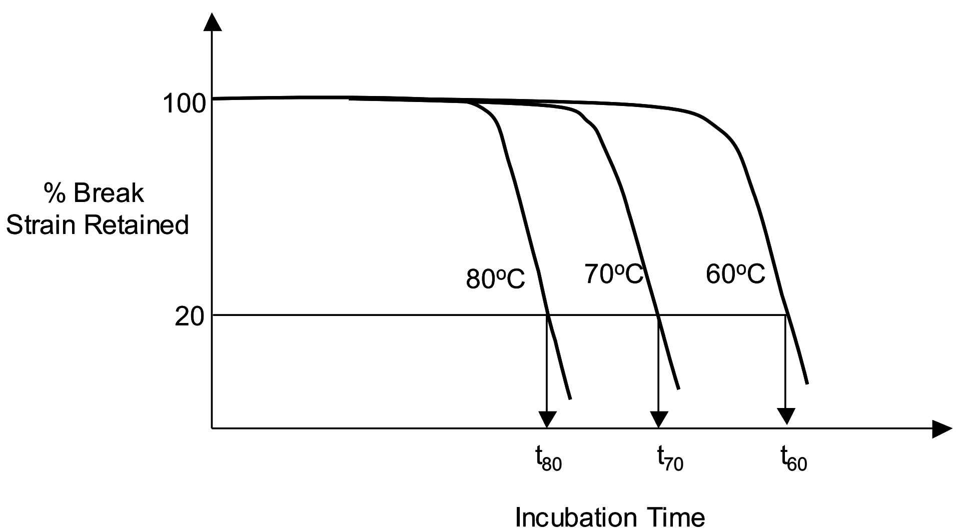


Figure 3 – Determine the time to reach 20% break strain retained

7.4 Determine the reaction rate at each incubation temperature using equation (4).

$$\textbf{Reaction Rate}\ (\boldsymbol{R}_{\textbf{temperature}}) = \frac{1}{\boldsymbol{t}_{\textbf{temperature}}} \qquad (4)$$

7.5 Perform Arrhenius plot by plotting ln($R_{temperature}$) versus ($1/T$). A data shall be fitted with a straight line.

7.6 The Arrhenius equation obtained from 6.5 shall be used to extrapolate the 80% drop in break strain at specific site temperature (t_{site}), which is the lifetime of the pipe based on oxidation degradation.

8 REPORTING RESULTS

8.1 Procedure A

8.1.1 Report the three individual OIT value

8.1.2 Report the average and the minimum OIT of the three values.

8.2 Procedure B

8.2.1 The material properties versus incubation time plot for all three incubation temperatures.

8.2.2 Report antioxidant depletion rate at each incubation temperature.

8.2.3 Report lifetime of antioxidant in years.

8.2.4 Report lifetime of the pipe based on oxidation degradation in years.

APPENDIX G

Florida Method of Test
for Determining Creep Rupture of
Corrugated Pipe Liner Tensile Specimens

Designation, FM 5-575

Florida Method of Test for Determining Creep Rupture of Corrugated Pipe Liner Tensile Specimens

Designation, FM 5-575

1. SCOPE

1.1 This test method is used to determine time-to-failure of HDPE corrugated pipe liner tensile specimens under constant applied stresses.

1.2 The test data generated on these specimens shall be analyzed according to Florida Method of Test for Predicting the Long-Term Tensile Strength of Corrugated High Density Polyethylene (HDPE) Pipes-FM 5-576.

1.3 The values stated in inch-pound units are to be regarded as the standard. The values given in parenthesis are mathematical conversions to SI units, which are provided for information only and are not considered standard.

2. REFERENCED DOCUMENTS

2.1 ASTM Standards:

D1600 Terminology for Abbreviated Terms Relating to Plastics

D 638 Test Method for Tensile Properties of Plastics

D 2990 Test Methods for Tensile, Compressive, and Flexural Creep and Creep-Rupture of Plastics

F2136 Standard Test Method for Notched Constant Ligament Stress (NCLS) Test to Determine Slow Crack Growth Resistance of HDPE Resins or HDPE Corrugated Pipe

F2018 Time-to-Failure of Plastics Using Plane Strain Tensile Specimens

2.2 Florida Standards

FM5-576 Test Method for Predicting Long-Term Tensile Strength of HDPE Corrugated Pipes

3. TEST METHOD

3.1 This test method consists of a description of the locations of test specimens in the liner section of the corrugated pipe and the creep rupture tests in a controlled-temperature water bath.

4. APPARATUS

4.1 Blanking Die - A die suitable for cutting test specimens to the dimensions and tolerances specified in ASTM D 638 Types IV or Type V. Type IV die shall be used for pipes with diameter from 42 to 60 inches. Type V die shall be used for pipes with diameter from 12 to 36 inches.

4.2 Creep Testing Apparatus. - A lever loading machine, with a lever arm ratio of 3:1 to 5:1 similar to that described in ASTM D 5397. Alternatively the tensile load may be applied directly using dead weights or any other method for producing a constant stress.

(Testing apparatus is available from BT Technology, Inc. 320 N. Railroad Street, Rushville, IL 62681, Materials Performance, Inc. 2151 Harvey Mitchell Pkwy, S. Suite 208, College Station, TX 77840, Satec Systems, 900 Liberty Street, Grove City, PA 16127, or equivalent.)

4.3 Micrometer (or caliper) capable of measuring to +/- 0.0005 in (+/- 0.0127 mm).

4.4 Metal shot for weight tubes.

4.5 Electronic scale for measuring shot weight tubes capable of measuring to +/- 0.0002 lbs. (0.1 g).

4.6 Timing device capable of recording failure time to the nearest 0.1 h.

5. SPECIMEN PREPARATION

5.1 Test specimens are to be die cut from the inner liner of the corrugated pipe. The specimens shall be oriented along the longitude axis of the pipe, as shown in Figure 1.

5.2 Five specimens shall be cut from same circumferential section of the test pipe but at locations of 70^{o} apart from each other.

5.3 The average thickness of each test specimen shall be determined by averaging three thickness measurements of the constant neck section.

6. CALCULATION

6.1 Calculate the stress of each test specimen as follows:

$$S = P/(W*t) \qquad (1)$$

Where:

S = applied stress (psi)
P = tensile load (lb or g)
W = width of specimen (in)
t = average thickness of the specimen (in)

6.2 Each test weight so determined is to be labeled (or otherwise correlated to each test position) and applied to the appropriate lever arm on the test apparatus.

7. PROCEDURE:

Maintain temperature in the bath at the incubation temperature, which shall be one of the four elevated temperatures: 50, 60, 70 or 80^{o}C.

7.2 Test five (5) specimens at each stress level, which ranges from 100 to 700 psi.

7.3 Determine the weight to be placed on each specimen, and load the weight tubes with shot. Do not attach the shot tube to the lever arm.

7.4 Attach the specimens to the loading frame. Take care that bending the specimen does not activate the notch. Lower the specimen into the bath, and condition the specimens in the bath for at least 60 minutes.

7.5 Reset the specimen timer to zero.

7.6 Check that the weight is the correct weight for the particular specimen, and carefully connect the weight tube to the appropriate lever arm for the specimen. Apply the load gradually within a period of 5 to 10 s without any impact on the specimen.

7.7 Start the specimen timer immediately after loading.

7.8 Record the time to failure of each specimen to the nearest 0.1 h.

8. REPORTING RESULTS

The test report shall include the following information:

8.1 Complete identification of the material tested (material type, manufacturer's name and code number).

8.2 The load placed on each lever as per equation in 6.1 and cross-sectional dimension of each specimen.

8.3 Test temperature

8.4 Report the failure time for each of the five specimens and the arithmetic average of each specimen set of five specimens.

8.5 Plot applied stress against average failure time in a log-log scale.

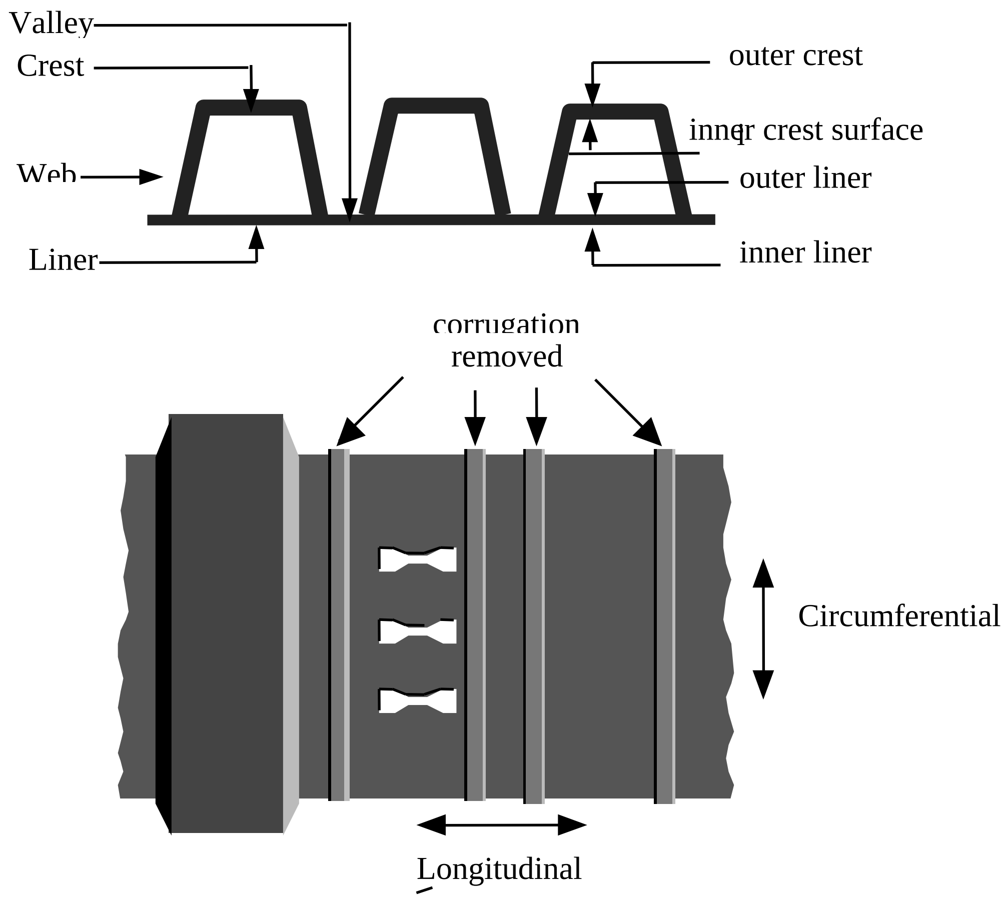


Figure 1 – Location of test specimens to evaluate tensile properties of pipe

APPENDIX H

Florida Method of Test
for Florida Method of Test
for Predicting Long-Term Tensile Strength
of HDPE Corrugated Pipes

Designation, FM 5- 576

Florida Method of Test for Predicting Long-Term Tensile Strength of HDPE Corrugated Pipes

Designation, FM 5-576

1. SCOPE

1.1 This test method is used to predict the long-term tensile strength of high density polyethylene corrugated pipes in view of Florida DOT 100-year design service life requirement.

1.2 The test utilizes creep rupture data obtained from FM 5-575 test method on pipe liner material.

1.3 The tests shall be performed at minimum of three different elevated temperatures in the incubation environment of water.

1.4 The creep rupture data obtained from the elevated temperatures are shifted to a lower site specific temperature using the equations defined by Popelar, et al., (1991)

2. REFERENCED DOCUMENTS

2.1 ASTM Standards:

D1600 Terminology for Abbreviated Terms Relating to Plastics

D 638 Standard Test Method for Tensile Properties of Plastics

D 2990 Test Methods for Tensile, Compressive, and Flexural Creep and Creep-Rupture of Plastics

F2136 Standard Test Method for Notched Constant Ligament Stress (NCLS) Test to Determine Slow Crack Growth Resistance of HDPE Resins or HDPE Corrugated Pipe

2.2 Florida Standards:

FM 5-575 Test Method for Determining Creep Rupture of HDPE Corrugated Pipes

2.3 Other Documents

Popelar, C.H., Kenner, V.H., and Wooster, J.P. (1991) “An Accelerated Method for Establishing the Long Term Performance of Polyethylene Gas Pipe Materials”, Polymer Engineering and Science, Vol. 31, No. 24, pp. 1693-1700.

3. CREEP RUPTURE TEST

3.1 The creep rupture test shall be performed according to the FM 5-575 using ASTM D 638 Type IV or Type V specimens.

3.2 The creep tests shall be tested in the environment of tap water.

Note 1 – In case of dispute, the water should be distilled or deionized.

3.3 The test temperatures shall range between 50 and 80°C. Test shall not be performed at a temperature exceeding 80°C. The SCR test shall be carried out at three different temperatures at 10°C interval between them.

3.4 Applied stresses shall range from 100 to 800 psi. At each test temperature, a minimum of four stress levels shall be tested at maximum increments of 100 psi. The applied stresses at different test temperatures are shown in Table 1.

Note 2 – Tests performed at stresses higher than the defined values may enter into the transition region of the ductile-brittle curve, yielding a longer failure time than that of the lower stress. Details of the ductile-brittle transition can be found in ASTM D5397.

3.5 Five specimens are tested at each stress level to produce statistically significant results.

Table 1 – Applied Stresses at Different Test Temperatures

Test Temperature (°C)	Applied Stresses (psi)
50	600 to 1000,
60	500 to 900,
70	400 to 800
80	300 to 700

4. DATA ANALYSIS

4.1 For each of the applied stresses, calculate the arithmetic mean of the three failure time values and report it as the "average failure time" for that particular applied stress.

4.2 For test specimens that do not fail after 2000 hours testing time, tests shall be terminated and recorded their failure times as 2000 hours.

4.3 Present test data in graphic form by plotting the logarithm of applied stress versus the logarithm of the average failure time for each test temperature. An example of the results is shown in Figure 1.

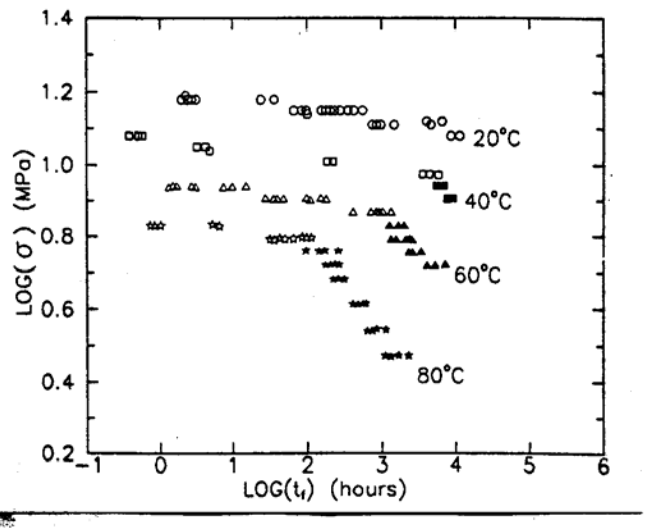


Figure 1 – An example to illustrate the results of SCR tests at three different temperatures (ref. Popelar, et al., 1991)

5. PREDICTION METHOD

5.1 The three sets of creep rupture data obtained from the elevated temperatures are shifted to a site specific temperature according to Equations (1) and (2) that are defined by Popelar, et al., (1991).

$$a_T = \exp[-0.109(T - T_R)] \quad (1)$$

$$b_T = \exp[0.0116(T - T_R)] \quad (2)$$

where:

a_T = *horizontal shift function (time function)*
b_T = *vertical shift function (stress function)*
T = *temperature of the test*
T_R = *target temperature (in this case this is site temperature)*

5.2 The average temperature of 23°C shall be used as the general site temperature in the lifetime extrapolation analysis.

5.3 Present all the shifted data in graphic form by plotting the logarithm of applied stress versus the logarithm of the average failure time at the site temperature. Figure 2 shows an example of the shifted data.

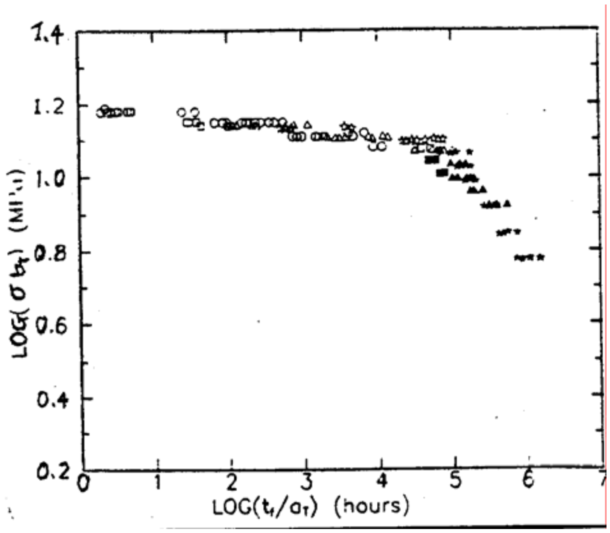


Figure 2 – An example of the shifted data from Figure 1

5.4 Apply power law equation to shifted data to obtain the best fitted curve. The resulting power law equation shall be used to predict the long-term tensile strength of the pipe. The general power law equation is shown as Equation (3).

$$\sigma = At^b \qquad (3)$$

Where:

σ	= *Applied stress (psi)*
t	= *Failure time (hr)*
A and b	= *Constants*

5.5 Substitute the expected axial tensile stress (σ) that is obtained from finite element analysis using the specific site design parameters into fitted equation to yield the failure time. The failure time shall be greater than 100 years (or 876,000 hours)

6. REPORTING RESULTS

The test report shall include the following information:

6.1 All details necessary for complete identification of the material tested (AASHTO M 294 cell class).

6.2 Test information and results shall be recorded according in the format shown in Table 2.

6.3 Report the shifted data, fitted power law equation and shifted graph.

6.4 The axial tensile stress used to calculate the failure time of the pipe during service lifetime.

Table 2 – Recommend Data Record Template

Applied Stress (psi)	Average Thickness (in)	Applied Load (lb)	Failure Time (hr)	Average Failure Time (hr)

APPENDIX I

Florida Method of Test for Predicting Long-Term Flexural Modulus of HDPE Corrugated Pipes

Designation, FM 5-577

Florida Method of Test for
Predicting Long-Term Flexural Modulus
of HDPE Corrugated Pipes

Designation, FM 5-577

1. SCOPE

1.1 This test method is used to predict the long-term flexural modulus of high density polyethylene corrugated pipes in view of Florida DOT 100-year design service life requirement.

1.2 The test utilizes stress relaxation data obtained from ASTM D2412 test method on corrugated pipes with diameter less than 24 inches.

1.3 The tests shall be performed at minimum of six elevated temperatures in the incubation environment of air.

1.4 The stress relaxation data obtained from the elevated temperatures are shifted to a lower site specific temperature using the equations defined by Popelar, et al., (1991)

2. REFERENCED DOCUMENTS

2.2 ASTM Standards:

D1600 Terminology for Abbreviated Terms Relating to Plastics

D 2412 Test Method for Determination of External Loading Characteristics of Plastic Pipe by Parallel-Plate Loading

2.2 Other Documents:

Popelar, C.H., Kenner, V.H., and Wooster, J.P. (1991) “An Accelerated Method for Establishing the Long Term Performance of Polyethylene Gas Pipe Materials”, Polymer Engineering and Science, Vol. 31, No. 24, pp. 1693-1700.

Selig, E.T (1995), “Long-Term Performance of Polyethylene Pipe under High Fill”, Geotechnical Report No. PDT95-424F, Technical Report – Part 2, Research Project No. 88-14, Pennsylvania Department of Transportation, Harrisburg, PA.

3. STRESS RELAXATION TEST

3.1 The stress relaxation test shall be performed based on ASTM D 2412 procedure with modifications as follows:

3.1.1 Compress the pipe specimen at a constant rate of 0.5 in/min until deflection reaches 5% of the average inside diameter of specimen.

Note 1 – The test apparatus can be simple metal frame equipment with a load cell that has the appropriate capacity to measure the changing load with time. Figure 1 is a test apparatus that was used by Selig (1995) for stress relaxation test on 24 inch corrugated pipes.

3.1.2 Hold the pipe at 5% deflection and monitor load changes with time.

3.1.3 Terminate the test after 24 hours.

Note 2 – the testing time may need to extend to a longer hour depending on the resulting Master curve at 23°C after shifting. The duration of the Master curve shall not be shorter than 10-years from which a 100-year modulus can be extrapolated.

3.2 The stress relaxation tests shall be tested in the environment of air at five elevated temperatures, ranging from 35 to 85°C at 10°C intervals.

3.4 Each test temperature shall be held at an accuracy of ±2°C.

Note 3 – The temperature chamber can be made from extruded polystyrene foam panels and are placed around the test pipe. The elevated temperatures can be achieved by forcing hot air into the incubation chamber.

4. DATA ANALYSIS

4.1 At each test temperature, the load changes with time shall be recorded for duration of 1000 hours.

4.2 The pipe stiffness, PS, shall be calculated according to the equation (1) which is defined in ASTM D 2412.

$$PS = \frac{F}{\Delta y}\left(1 + \frac{\Delta y}{2d}\right)^3 \quad (1)$$

where: F = applied load per unit length (lb/in)
Δy = inside vertical diameter change (in), and
d = initial inside vertical diameter

4.3 The flexural modulus of the pipe at 5% deflection shall be calculated using equation (2) which is defined in ASTM D 2412.

$$E = \frac{0.149 r^3 (PS)}{I} \quad (2)$$

where: E = flexural modulus
r = half the sum of the inner diameter and one corrugation depth
I = bending moment

4.4 Present test data in graphic form by plotting the logarithm of flexural modulus versus the logarithm of the testing time for each temperature. An example of the results is shown in Figure 2.

4.5 The five sets of stress relaxation data obtained from the elevated temperatures are shifted to a 23°C temperature according to Equations (3) and (4) that are defined by Popelar, et al., (1991), yielding a master curve at 23°C. An example of the results is shown in Figure 3 at reference temperature of 27.5°C.

$$a_T = \exp[-0.109(T - T_R)] \quad (3)$$

$$b_T = \exp[0.0116(T - T_R)] \quad (4)$$

where:

a_T = *horizontal shift function (time function)*
b_T = *vertical shift function (stress function)*
T = *temperature of the test*
T_R = *target temperature (in this case this is site temperature)*

4.6 The duration of the resulting master curve must be longer than 10-year. If the duration of the master curve is shorter than 10-year, a new set of stress relaxation tests shall be performed by extending the individual testing time from 24 hours to 48 hours.

4.7 The master curve at 20°C shall be fitted with a power law equation, as displaced in Figure 3, from which the 100 year modulus value can be predicted.

5. REPORTING RESULTS

Test report shall include the following information:

5.1 All details necessary for complete identification of the material tested (AASHTO M 294 cell class).

5.2 Test temperatures and modulus versus time curve at each temperature.

5.3 Report the shifted data, fitted power law equation and shifted graph with master curve.

5.4 Report predicted modulus value at 100-year using the power law equation.

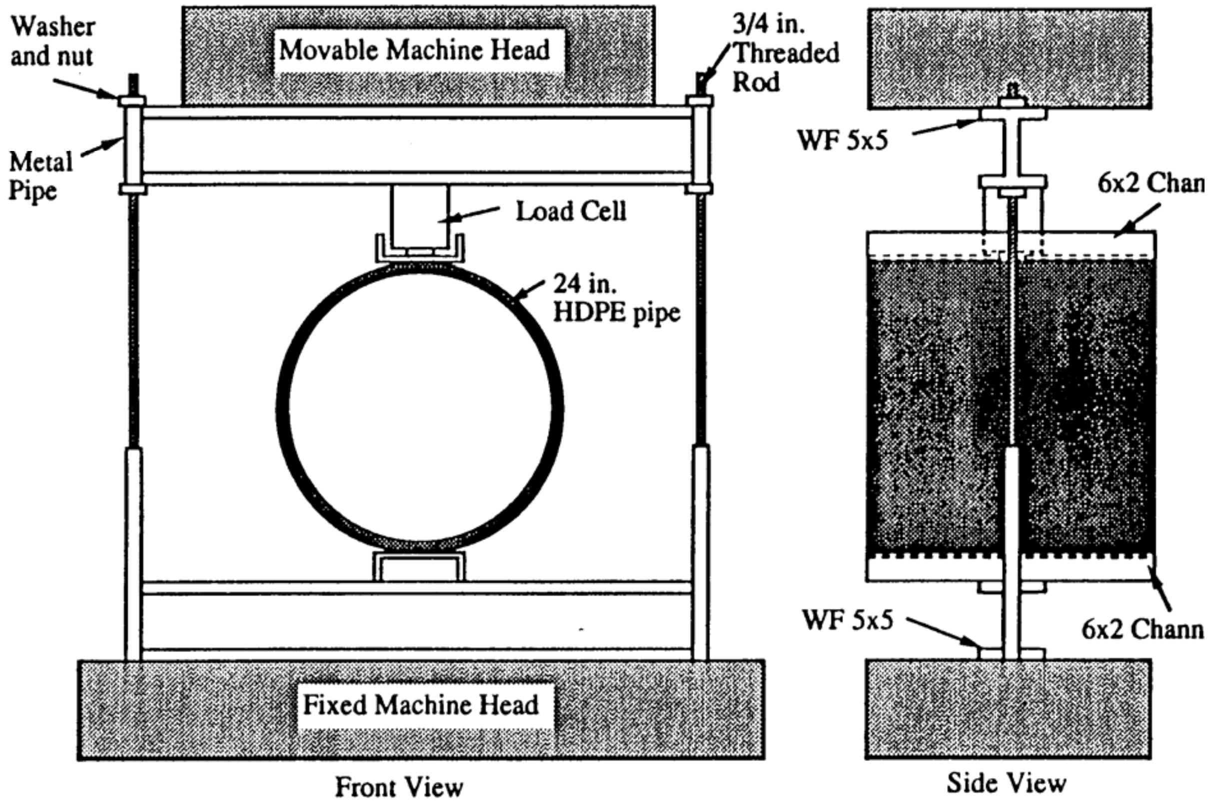


Figure 1 – Parallel Plate test set up for stress relaxation test of corrugated pipe, (Selig, 1995)

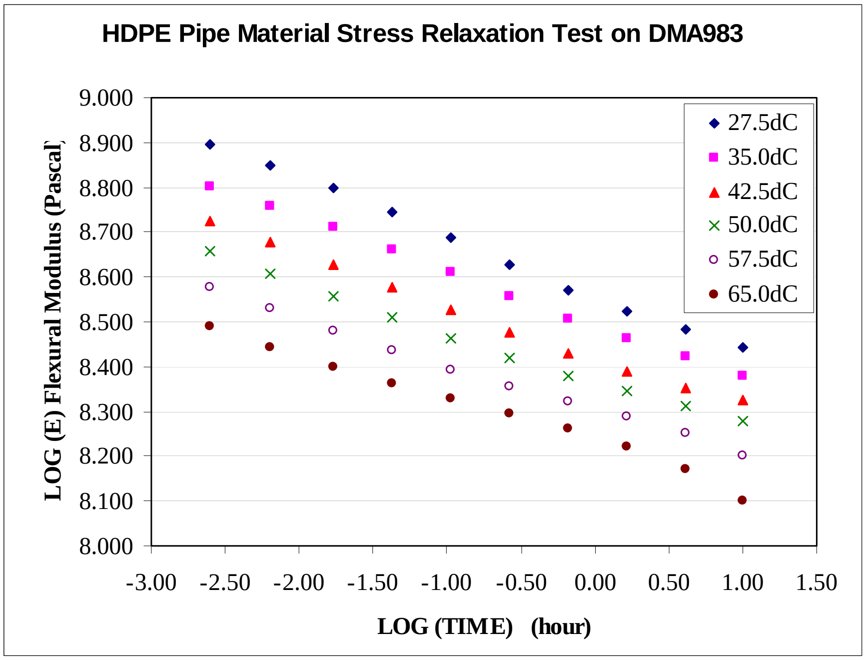


Figure 2 - Stress relaxation curves resulted from the DMA test-1

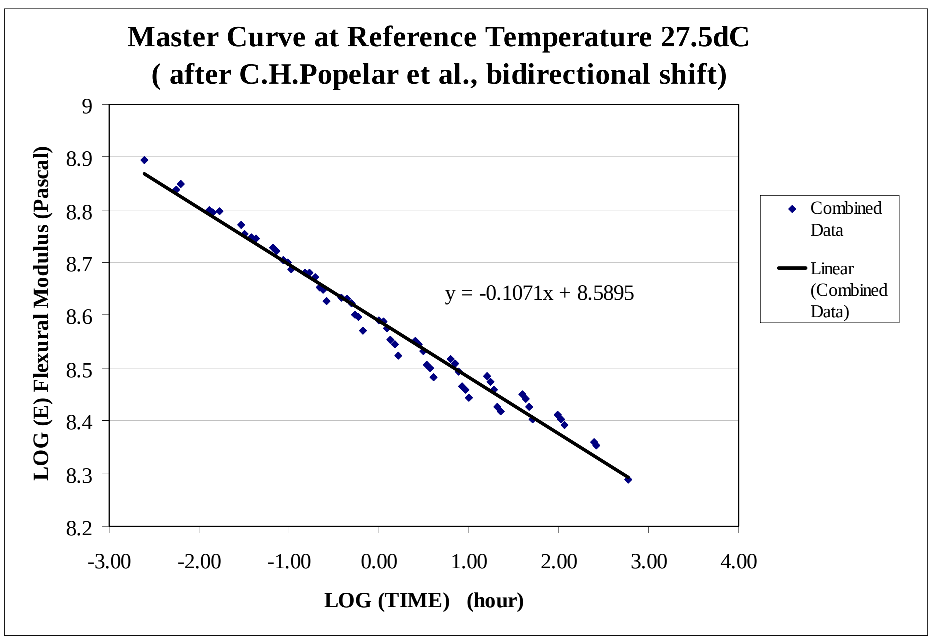


Figure 3 - Master curve at 27.5 after shifted using Popelar factors

APPENDIX J

An Outline of the Full Specification

for

100-Year Service Life of High Density Polyethylene Corrugated Pipes

An Outline of the Full Materials Specification for 100-year Service Life of Corrugated High Density Polyethylene Pipes

1 Scope

1.1 This specification covers the requirements and methods of tests for corrugated polyethylene (PE) pipe, use in surface and subsurface drainage applications.

1.2 Nominal sizes of 300 to 1200 mm are included.

1.3 Materials including slow crack growth resistance, antioxidant content and depletion rate, long-term tensile strength and flexural modulus, workmanship, dimensions, pipe stiffness, and form of markings are specified.

1.4 Corrugated polyethylene pipe is intended for surface and subsurface drainage applications where soil provides support to its flexible walls. Its major use is to collect or convey drainage water by open gravity flow, as culverts, storm drains, etc.

1.5 This specification does not include requirements for bedding, backfill, or earth cover load. Successful performance of this product depends upon proper type of bedding and backfill, and care in installation. The structural design of corrugated polyethylene pipe and the proper installation procedures are given in the AASHTO's *Standard Specifications for Highway Bridges*. Upon request of the user or engineer, the manufacturer shall provide profile wall section detail required for a full engineering evaluation.

2 REFERENCED DOCUMENTS

2.1 AASHTO Standards:

- Standard Specifications for Corrugated Polyethylene Pipe: M294
- Standard Specification for Highway Bridges LRFD Bridge Design Specification

2.2 ASTM Standards*:*

- D 618, Conditioning Plastics and Electrical Insulating Materials for Testing
- D 638, Standard Test Method for Tensile Properties of Plastics
- D 883, Terms Relating to Plastics
- D4703, Standard Practice for Compression Molding Thermoplastic Materials into Test Specimens, Plaques, or Sheets
- D 2122, Determining Dimensions of Thermoplastic Pipe and Fittings
- D 2412, Determination of External Loading Characteristics of Plastic Pipe by Parallel-Plate Loading
- D 2444, Test for Impact Resistance of Thermoplastic Pipe and Fittings by Means of a Tup (Falling Weight)
- D 2990 Test Methods for Tensile, Compressive, and Flexural Creep and Creep-Rupture of Plastics

- D 3350, Standard Specification for Polyethylene Plastics Pipe and Fittings Materials
- D 3895, Standard Test Method for Oxidative-Induction Time of Polyolefins by Differential Scanning Calorimetry
- F2136 Standard Test Method for Notched Constant Ligament Stress (NCLS) Test to Determine Slow Crack Growth Resistance of HDPE Resins or HDPE Corrugated Pipe
- F 412, Terms Relating to Plastic Piping Systems

2.3 Florida Test Standard*:*

- FM 5-572, Standard Test for Determining Slow Crack Growth Resistance of HDPE Corrugated Pipes
- FM 5-573, Standard Test Method for Predicting the Crack Free Service Life of HDPE Corrugated Pipes
- FM 5-574, Standard Test Method for Predicting the Lifetime of Antioxidants and HDPE Corrugated Pipes
- FM 5-575, Standard Test Method for Determining Creep Rupture of Corrugated Pipe Liner Tensile Specimens
- FM 5-576, Standard Test Method for Predicting Long-Term Tensile Strength of HDPE Corrugated Pipes
- FM 5-577, Standard Test Method for Predicting Long-Term Flexural Modulus of HDPE Corrugated Pipes

3 TERMINOLOGY

3.1 The terminology used in this standard is in accordance with the definitions given in ASTM D 833 and ASTM F 412 unless otherwise specified

3.2 Crack – any break or split that extends through the wall

3.3 Stress-crack – an external or internal crack in a plastic caused by tensile stresses less than its short-time mechanical strength

Discussion – The development of such cracks is frequently accelerated by the environment to which the plastic is exposed. The stresses which cause cracking may be present internally or externally or may be combinations of these stresses.

3.4 Crease – An irrecoverable indentation, generally associated with wall buckling

3.5 Buckling – Any reverse curvature or deformation in the pipe wall that reduces the load-carrying capability of the pipe

3.6 Longitudinal Profiles – (Added terminology) Longitudinal profile(s) include any feature that runs along the longitudinal axis of the pipe in either continuously or repeating in regular intervals. These features may be a part of the pipe design (for example vent holes or mold line) or those resulting from extrusion defects.

3.7 Polyethylene (PE) – Plastics based on polymers made with ethylene as the primary monomer.

3.8 Reworked Material – as defined for “reworked plastic (thermoplastic)” in ASTM D 883.

3.9 Virgin Polyethylene Material – PE plastic material in the form of pellets, granules, powder, floc, or liquid that has not been subject to use or processing other than required for initial manufacture.

4 CLASSIFICATION

4.1 The corrugated polyethylene pipe covered by this specification is classified as follows:

4.1.1 Type S – This pipe shall have a full circular cross section, with an outer corrugated pipe wall and a smooth inner liner. Corrugations shall be annular.

4.1.2 Type SP – This pipe shall be Type S with perforations.

4.2 Two classes of perforations are as described in Sections 6.3.1 and 6.3.2.

5 MATERIALS

5.1 Resin Materials

5.1.1 Extruded Pipe – Pipe shall be made of virgin PE compounds which conform with the requirements of cell class 335400C as defined and described in ASTM D 3350, except that the carbon black content shall not exceed 5 percent, and the density shall not be less than 0.945 gm/cc nor greater than 0.955 gm/cc. Compounds that have higher cell classifications in one or more properties, with the exception of density, are acceptable provided product requirements are met. For slow crack growth resistance, resins shall be evaluated using the notched constant ligament stress (NCLS) test (ASTM F2136). The average failure time of the five test specimens must exceed 24 hours with no single test specimen’s failure time less than 17 hours.

5.1.2 Reworked Material – In lieu of virgin PE, clean reworked material may be used by the manufacturer, provided that it meets the cell class requirements and exceptions as described in Section 6.1.1.

6 REQUIREMENTS

6.1 Workmanship – The pipe and fittings shall be free of foreign inclusions and visible defects as defined herein. The ends of the pipe shall be cut squarely and cleanly so as not to adversely affect joining or connecting.

6.1.1 Visible Defects – Cracks, creases, notches and similar extrusion defects, unpigmented or nonuniformly pigmented pipe are not permissible in the pipe or fittings as furnished.

6.1.2 For Type S pipe, the inner liner shall be fused to the outer corrugated shell at all internal corrugation crests.

6.2 Pipe Dimensions:

6.2.1 Nominal Size – The nominal size for the pipe is based on the nominal inside diameter of the pipe.

6.2.2 Wall Thickness – The inner wall of the Type S pipe shall have the following minimum thicknesses, when measured in accordance with Section 8.9.4

Diameter (in)	Wall Thickness (in)
12	0.035
15	0.040
18	0.051
21	0.059
24	0.059
27	0.059
30	0.059
35	0.067
41	0.07
47	0.07

6.2.3 Inside Diameter Tolerances – The tolerance on the specified inside diameter shall be 4.5 percent oversize and 1.5 percent undersize, but not more than 1.12 in oversize when measured in accordance with Section 8.9.1

6.2.4 Length – Corrugated PE pipe may be sold in any length agreeable to the user. Lengths shall not be less than 99 percent of the stated quantity when measured in accordance with Section 8.9.2.

6.3 Perforations – When perforated pipe is specified, the perforations shall conform to the requirements of Class 2, unless otherwise specified in the order. Class 1 perforations are for pipe intended to be used for subsurface drainage or combination storm and underdrain. Class 2 perforations are for pipe intended to be used for subsurface drainage only. The perforations shall be cleanly cut so as not to restrict the inflow of water. Pipe connected by couplings or bands may be non-perforated within 4 inches of each end of each length of pipe. Pipe connected by bell and spigot joints may not be perforated in the area of the bells and spigots.

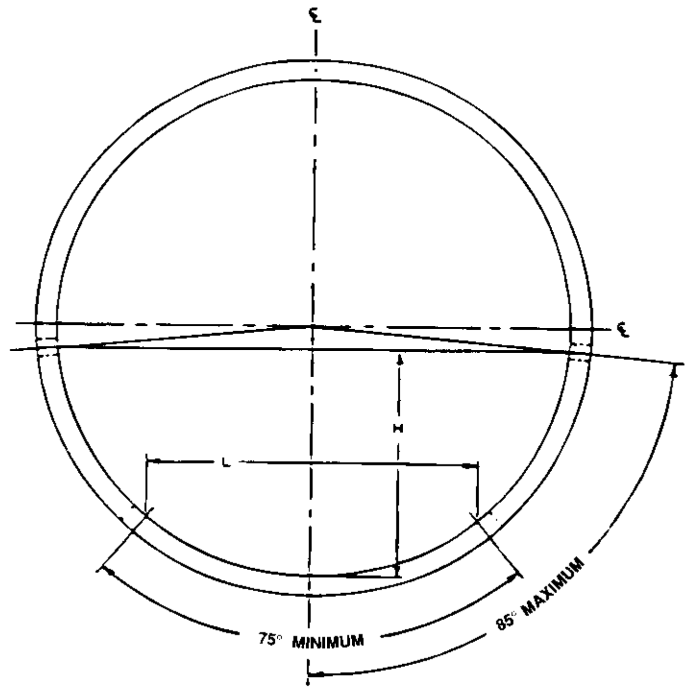


Figure 1—Requirements for Perforations

Table 1—Rows of Perforations, Height "H" of the Centerline of the Uppermost Rows above the Invert, and Chord Length "L" of Unperforated Segment, for Class 1 Perforations

Nominal Diameter (in)	Rows of Perforations[A]	H Maximum[B] (in)	L Minimum[B] (in)
12	6	5.4	7.6
15	6	7.2	10
18	6	8.1	11.3
21	6	9.1	12.6
24	8	([c])	([c])

A Minimum number of rows. A greater number of rows for increased inlet area shall be subject to agreement between purchaser and manufacturer.
Note: The number of perforations per inch in each row (and inlet area) is dependent on the corrugation pitch.

B See Figure 1 for location of dimensions "H" and "L"

C H (max.) = 0.46D; L (min.) = 0.64, where D = nominal diameter of pipe (in)

6.3.1 Class 1 Perforations — The perforations shall be approximately circular and shall have nominal diameters of not less than 0.2 in nor greater than 0.4 in and shall be arranged in rows parallel to the axis of the pipe. The perforations shall be located in the external valleys with perforations in each row for each corrugation. The rows of perforations shall be arranged in two equal groups placed symmetrically on either side of the lower unperforated segment corresponding to the flow line of the pipe. The spacing of the rows shall be uniform. The distance between the center lines of the rows shall not be less than 1 in. The minimum number of longitudinal rows of perforations, the maximum height of the center lines of the uppermost rows of perforations above the bottom of the invert, and the inside chord lengths of the unperforated segments illustrated in Figure 1 shall be as specified in Table 1.

6.3.2 Class 2 Perforations — Circular perforations shall be a minimum of 0.2 in and shall not exceed 0.4 in. in diameter. The width of slots shall not exceed 0.12 in. The length of slots shall not exceed 2.8 in for 12 in and 15 in pipe and 3 in for 18 in and larger pipe. Perforations shall be placed in the external valleys and uniformly spaced along the length and circumference of the pipe. The water inlet area shall be a minimum of 30 cm^2/m for pipe sizes 12 to 18 in and 40 cm^2/m for pipe sizes larger than 18 in. All measurements shall be made in accordance with Section 8.9.3.

6.4 Pipe Stiffness – The pipe shall have a minimum pipe stiffness at 5 percent deflection as follows when tested in accordance with Section 8.1.

Diameter (in)	Pipe Stiffness (psi)
12	50
15	42
18	40
21	38
24	34
27	30
30	28
35	22
41	20
47	18

6.5 Pipe Flattening — There shall be no evidence of wall buckling, cracking, splitting, or delaminating, when the pipe is tested in accordance with Section 8.2.

6.6 Brittleness — Pipe specimens shall not crack or split when tested in accordance with Section 8.3. Five non-failures out of six impacts will be acceptable.

6.7 Environmental Stress Cracking — The pipe shall be test according to Section 8.4.

6.8 Oxidation Resistance – The pipe shall be test according to Section 8.5

6.9 Long-term Tensile Strength – The 100-year tensile strength shall be determined according to Section 8.6.

6.10 Long-term Flexural Modulus – The 100-year tensile strength shall be determined according to Section 8.7.

6.11 Fitting Requirements*:*

6.11.1 The fittings shall not reduce or impair the overall integrity or function of the pipe line.

6.11.2 Common corrugated fittings include in-line joint fittings, such as couplings and reducers, and branch or complimentary assembly fittings such as tees, wyes, and end caps. These fittings are installed by various methods.

Note 1 — Only fittings supplied or recommended by the pipe manufacturer should be used. Fabricated fittings made from pipe meeting the requirements of the pipe specification should be acceptable providing that the joints are adequately lapped or reinforced. Soil tightness is a function of opening size, channel length, and backfill particle size. A backfill material containing a high percentage of fine-graded soils requires investigation for the specific type of joint to be used to guard against soil infiltration. Information regarding joint soil tightness criteria can be found in AASHTO's *Standard Specifications for Highway Bridges*, Division II, Section 26, "Metal Culverts."

6.11.3 All fittings shall be within an overall length dimensional tolerance ±0.5 in of the manufacturer's specified dimensions when measured in accordance with Section 8.9.2.

6.11.4 Fittings shall not reduce the inside diameter of the pipe being joined by more than 0.5 in. Reducer fittings shall not reduce the cross-sectional area of the small size.

6.11.5 Couplings shall be corrugated to match the pipe corrugations and shall provide sufficient longitudinal strength to preserve pipe alignment and prevent separation at the joints. Couplings shall be bell and spigot, split collar, or screw-on collar. Split couplings shall engage at least two full corrugations on each pipe section.

6.11.6 Pipe connections shall not separate to create a gap exceeding 0.2 in when measured in a radial direction between pipe and coupling, or between bell and spigot portions of pipe, when tested according to Section 8.8.1. Fittings shall not crack or delaminate.

6.11.7 The design of the fittings shall be such that when connected with the pipe, the axis of the assembly will be level and true when tested in accordance with Section 8.8.2.

6.11.8 Other types of coupling bands or fastening devices which are equally effective as those described, and which comply with the joint performance criteria of AASHTO's *Standard Specifications for Highway Bridges*, Division II, Section 26, may be used when approved by the purchaser.

7 CONDITIONING

7.1 Conditioning – Condition the specimen prior to test at 21 to 25°C for not less than 40 hours in accordance with Procedure A in ASTM D 618 for those tests where conditioning is required, and unless otherwise specified

7.2 Conditions — Conduct all tests at a laboratory temperature of 21 to 25°C unless otherwise specified herein.

8 TEST METHODS

8.1 Pipe Stiffness - Select a minimum of three (3) pipe specimens and test for pipe stiffness (PS), as described in ASTM D 2412 except for the following: (1) the test specimens shall be a minimum of one diameter length; (2) locate the first specimen in the loading machine with an imaginary line connecting the two seams formed by the corrugation mold (end view) parallel to the loading plates, when applicable. The specimen must lie flat on the plate within 3 mm and may be straightened by hand bending at room temperature to accomplish this. Use the first location as a reference point for rotation and testing of the other two specimens. Rotate subsequent specimens 45 and 90 degrees, respectively, from the original orientation. Test each specimen in one position only; (3) the deflection indicator shall be readable and accurate to ±0.0008 in; (4) the residual curvature found in tubing frequently results in an erratic initial load/deflection curve. When this occurs, the beginning point for deflection measurement shall be at a load of 4.5 ± 1 lb. The point shall be considered as the origin of the load deflection curve.

Note 2—The parallel plates must exceed the length of the test specimen as specified above.

8.2 Pipe Flattening — Flatten the three-pipe specimens from Section 8.1 until the vertical inside diameter is reduced by 20 percent. The rate of loading shall be the same as in Section 8.1. Examine the specimen with the unaided eye for cracking, splitting, or delamination. Wall buckling is indicated by reverse curvature in the pipe wall accompanied by a decrease in load carrying-ability of the pipe.

8.3 Brittleness — Test pipe specimens in accordance with ASTM D 2444 except six specimens shall be tested, or six impacts shall be made on one specimen. In the latter case, successive impacts shall be separated by 120 ± 10 degrees for impacts made on one circle, or at least 12 in longitudinally for impacts made on one element. Impact points shall be at least 6 in from the end of the specimen. Tup B shall be used, with a mass of 1 lb. The height of drop shall be 10 ft. Use a flat plate specimen holder. Condition the specimens for 24 hours at a temperature of 14 ± 2ºC, and conduct all tests within 60 seconds of removal from this atmosphere. The center of the falling tup shall strike on a corrugation crown for all impacts.

8.4 Environmental Stress Crack — Test different parts of the pipe for environmental stress cracking in accordance with FM 5-572 and FM 5-573. The summary of tests is shown in Table 2-Part I.

8.4.1 Pipe Liner – The evaluation of pipe liner shall be according to FM 5-572, procedure A. Five specimens shall be tested and the average failure time shall be based on the recommendation from the NCHRP 4-26

8.4.2 Pipe Junction – The test procedure shall be according to FM 5-572, Procedure B and FM 5-573. The failure time at 500 psi applied load at 23^{o}C shall exceed 100 year.

8.4.3 Pipe Longitudinal Profile – The test procedure shall be according to FM 5-572, Procedure C and FM 5-573. The failure time at 500 psi applied load at 23°C shall exceed 100 year.

8.5 Oxidation Resistance – Test pipes for their antioxidant contents and depletion rates to determine lifetime of antioxidant and corrugated pipe

8.5.1 Antioxidant Content – Determine the amount of antioxidants in the pipe using oxidative induction time (OIT) according to ASTM D 3895 and FM 5-574. The initial OIT of pipe is tentatively defined at 25 min. as indicated in the interim specification. The value shall be changed based on results of the long-term oxidative resistance test of the pipe.

8.5.2 Antioxidant Lifetime – Determine the lifetime of antioxidants in the pipe using OIT test and elevated temperature incubation according to procedures described in FM 5-574, as defined in Table 2-Part II.

8.5.3 Lifetime of Pipe – The thermal oxidation degradation of pipe shall be determined according to FM 5-574, as defined in Table 2-Part II. The lifetime of a pipe is defined at 80% decrease in breaking strain and shall exceed 100 year.

8.6 Long-term Tensile Strength – The 100 year tensile strength of pipe shall be determined according to FM 5-575 and FM 5-576. The tests shall be performed on pipe liner at three elevated temperatures at 65, 75 and 85°C. The test conditions are defined in Table 2-Part III.

8.7 Long-term Flexural Modulus – The 100 year flexural modulus of pipe shall be determined according to FM 5-577. The stress relaxation test shall be carried out based on parallel plate test (ASTM D 2412). The test is limited to pipe diameter of 24 inches. The test conditions are defined in Table 2-Part IV.

8.8 Joints and Fittings

8.8.1 Joint Integrity — Assemble each fitting or coupling to the appropriate pipe in accordance with the manufacturer's recommendations. Use pipe samples at least 300 mm in length. Assemble a specimen at least 600 mm in length with the connection at the center. Load the connected pipe and fitting between parallel plates at the rate of 0.5 in per minute until the vertical inside diameter is reduced by at least 20 percent of the nominal diameter of the pipe. Inspect for damage while at the specified deflection and after load removal. Measure the maximum radial distance between pipe and fittings, or between bell and spigot, during test and after load removal.

8.8.2 Alignment — Assure that the assembly or joint is correct and complete. If the pipe is bent, it should be straightened prior to performing this test. Lay the assembly or joint on a flat surface and verify that it will accommodate straight-line flow.

8.9 Dimensions

8.9.1 Inside Diameter — Measure the inside diameter of the pipe with a tapered plug in accordance with ASTM D 2122. As an alternative, measure the inside diameter with a suitable device accurate to ±0.12 in on two sections. Take eight measurements equally spaced around the circumference of each section and average these 16 measurements. The average inside diameter shall meet the requirements of Section 6.2.3.

8.9.2 Length — Measure pipe with any suitable device accurate to ±0.24 in. in 10 ft. Make all measurements on the pipe while it is stress-free and at rest on a flat surface in a straight line.

8.9.3 Perforations — Measure dimensions of perforations on a straight specimen with no external forces applied. Make linear measurements with instruments accurate to 0.008 in.

8.9.4 Wall Thickness — Measure the wall thickness in accordance with ASTM D 2122.

9 INSPECTION AND RETEST

9.1 Inspection – Inspection of the material shall be made as agreed upon by the purchaser and the seller as part of the purchase contract.

9.2 Retest and Rejection — If any failure to conform to these specifications occurs, the pipe or fittings may be retested to establish conformity in accordance with agreement between the purchaser and seller. Individual results, not averages, constitute failure.

10 MARKING

10.1 All pipe shall be clearly marked at intervals of no more than 12 ft as follows:

10.1.1 Manufacturer’s name or trademark,

10.1.2 Nominal size,

10.1.3 This specification designation, FL-DOT Specification XX,

10.1.4 The plant designation code, and

10.1.5 The date of manufacture or an appropriate code.

10.1.6 Fittings shall be marked with the designation number of this specification, FL-DOT Specification XX, and with the manufacturer’s identification symbol.

11 QUALITY ASSURANCE

11.1 A manufacturer’s certificate that the product was manufactured, tested, and supplied in accordance with this specification, together with a report of the test results, and the date each test was completed, shall be furnished upon request. Each certification so furnished shall be signed by a person authorized by the manufacturer.

Table 2 – Full Specification for Long-Term Performance of Corrugated HDPE Pipe

Pipe Location	Test Method	Test Conditions	Requirement
Part I – Stress Crack Properties of Pipe			
Pipe Liner	FM 5-572, Procedure A	10% Igepal solution at 50°C 600 psi and applied stress 5 replicates	Average failure time of the pipe liner shall be ≥17 hours; no single value shall be less than 12 hours.
Pipe Corrugation* (molded plaque)	ASTM F 2136	10% Igepal solution at 50°C 600 psi applied stress	Average failure time shall be ≥24 hours; no single value shall be less than 17 hours.
Junction**	FM 5-572, Procedure B and FM 5-573 ASTM D 2837	Test temperature 80°C and applied stresses of 650 and 450 psi. Test temperature 70°C and applied stress of 650 psi 5 replicates at each stress level	Calculate three constants Failure time at 500 psi at 23°C ≥ 100 years (95% statistical confidence)
		Single Test: Test temperature 80°C and applied stress of 650 psi. 5 replicates	The failure time must be equal or greater than the calculated value using the three constants from the three points test
Longitudinal Profile**	FM 5-572, Procedure C, and FM 5-573 ASTM D 2837	Test temperature 80°C and applied stresses of 650 and 450 psi. Test temperature 70°C at applied stress of 650 psi 5 replicates at each stress level	Calculate three constants Failure time at 500 psi at 23°C ≥ 100 years (95% statistical confidence)
		Single Test: Test temperature 80°C and applied stress of 650 psi., 5 replicates	The failure time must be equal or greater than the calculated value using the three constants from the three points test
Part II – Oxidation Resistance of Pipe			
Liner and/or Crown	OIT Test (ASTM D 3895)	2 replicates (to determine initial OIT value)	25 minutes, minimum
Liner and/or Crown	Incubation test FM 5-574, Procedure A, and ASTM D 3895	Three samples for incubation of 187 days at 85°C and applied stress of 250 psi. One OIT test per each sample.	Average OIT value shall be ≥3 minutes (no single value shall be less than 2 minutes)

Table 2 – Continue

Pipe Location	Test Method	Test Conditions	Requirement
Part III – Long-Term Tensile Strength			
Liner	FM 5-575 and FM 5-576	• Creep rupture test in water at 65, 75 and 85°C • Applied stress see Table 1 • Generate brittle curve at each test temperature	• Shift elevated temperature data to 23°C • Determine tensile strength at 100 year
Part IV – Long-Term Flexural Modulus			
Pipe	FM 5-577	• Stress relaxation test in air from 35 to 85°C • Obtain the modulus versus time curve at each temperature	• Shift elevated temperature data to 23°C • Determine modulus value at 100 year