AGING OF HDPE CONDUIT: EVALUATION OF 20-YEAR-OLD CONDUIT

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The Voice of an Industry.

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Foreword

This technical report was developed and published with the technical help and financial support of the members of the Plastics Pipe Institute. The members have shown their interest in quality products by assisting independent standard-making and user organizations in the development of standards, and also by developing reports on an industry-wide basis to help engineers, code officials, specifying groups, and users.

This technical report has been prepared to provide information to those responsible for the selection and installation of HDPE conduit. The report provides information on the properties of 20-year-old exhumed HDPE conduit with comparison to original and current specifications. This document is not intended to provide system design information. The reader is referred to the PPI website at www.plasticpipe.org for system design documents.

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1.0 BACKGROUND

HDPE conduit is used to provide a re-useable and protective pathway to house telecommunications and electrical cables. The long-term integrity of a conduit is important to protect the cable during its service life. At the end of the cable service life, the cable may be replaced with a new cable thus further extending the long-term performance requirement of the conduit.

Depending on the application and installation method, conduit is potentially subject to earth loads, ground movements, bending, compression and elevated temperatures while in-service. It is the toughness of HDPE conduit that makes it durable under these conditions. The purpose of this project is to demonstrate the long-term enduring toughness of HDPE conduit.

The materials and installation methods used to install conduit have evolved considerably over time; beginning with wood, terracotta tile, cast concrete, iron pipe, and galvanized steel, bringing us to today with the material of choice being thermoplastics. Beginning in the 1960s, the two primary thermoplastic materials used in extrusion, which is the process used to manufacture conduit, have been HDPE and PVC (polyvinylchloride). The industry experienced a significant increase in demand for HDPE conduit when telephone companies sought to add capacity in major metropolitan areas by removing traditional copper cables and replacing them with small diameter, fiber optic cables.

Whether it is above or below ground, HDPE conduit continues to be the material of choice as utilities expand their distribution infrastructure in urban and rural areas, and as communication companies increase availability of network bandwidth to meet the needs of the connected population.

Although HDPE conduit has been in service for over 50 years, no study of the long-term performance was found. This Technical Report summarizes the findings of testing 20-year-old exhumed HDPE conduit, with comparison to original and current performance specifications.

2.0 OBJECTIVE

The objective was to assess exhumed conduit for any changes in mechanical properties impacting long term performance. The aim was to obtain samples of conduit with at least 15 years of service in conduit applications. The measured mechanical properties of the conduit would be compared to the ASTM specification at the time of manufacturing and with current specifications to identify any changes incurred through aging.

3.0 SAMPLE

One sample of conduit was obtained. It was manufactured in 2001 per the 2001 edition of ASTM F2160 *Standard Specification for Solid Wall High Density Polyethylene (HDPE) Conduit Based on Controlled Outside Diameter (OD)*[i] and is believed to have been in service for most of the time until it was exhumed, totaling approximately 20 years. The sample is described in Table 1 and shown in Figures 1 through 3. The conduit had been in service carrying broadband communications and was extracted from a utility vault.

Table 1: Description of Exhumed and Tested Sample

Description	Line Print	Manufacturing Date
1¼ Yellow HDPE Duct	DURA-LINE 1-1/4" SDR-9 HDPE INNERDUCT M-18 A/5 01/17/01	January 17, 2001

Figure 1: Sample of Exhumed Conduit

Figure 2: Print Line of Exhumed Conduit

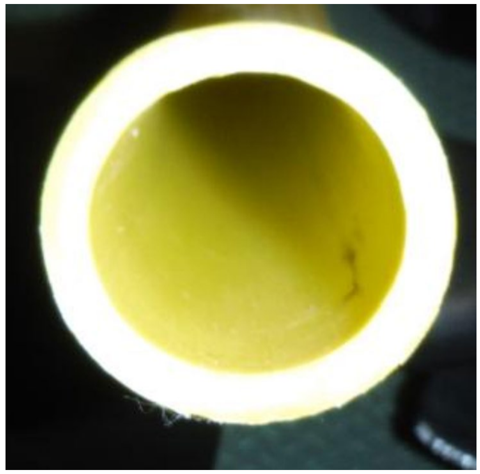

Figure 3: End View of Exhumed Sample

4.0 TESTING

The exhumed conduit sample was tested by an accredited laboratory, TRI Environmental, TX, USA, in late 2020 and early 2021. Testing was conducted in accordance with the requirement of the 2001 and 2016 editions of ASTM F2160 *Standard Specification for Solid Wall High Density Polyethylene (HDPE) Conduit Based on Controlled Outside Diameter (OD)*[1]. Material properties were verified using the methods prescribed by ASTM D3350 *Standard Specification for Polyethylene Plastics Pipe and Fittings Materials*[ii].

Most test methods and requirements remained unchanged between editions; however, changes, where they occurred, are noted in Section 5 and discussed in Section 6.

Additionally, the following non-ASTM F2160 tests were conducted to further characterize the aged conduit:

- Oxidation Induction Time of the inside surface per ASTM D3895 *Standard Test Method for Oxidative-Induction Time of Polyolefins by Differential Scanning Calorimetry*[iii]
- Bend-Back test per ASTM D2513-01 *Standard Specification For Polyethylene (PE) Gas Pressure Pipe, Tubing, And Fittings*[iv]

[1] As of the publication of this TR in 2023, there have been no significant changes to the ASTM F2160-16 requirements.

5.0 RESULTS

Tables 2 through 4 provide the requirements and test results.

- Table 2 provides the results of the material tests as specified by the standard ASTM F2160-01 and the standard ASTM F2160-16 (minimum cell classification PE334480E). The Melt Index requirements became more restrictive between the 2001 and 2016 editions. All other material requirements are unchanged.
- Table 3 provides the requirements and results of the dimensional measurements and the physical tests of the conduit. There are no changes in the dimensional requirements of Outside Diameter, Wall Thickness or Ovality between the 2001 and 2016 edition. The Stiffness and Compression & Recovery tests were introduced only in the 2016 edition. The Low Temperature Impact (-4 °F) requirement is unchanged.
- Table 4 reports the results of non-ASTM F2160 tests selected to assess the risk of inner surface embrittlement and cracking of the exhumed conduit. The Oxidation Induction Time test is a measure of the stabilizers remaining in the polymer matrix and the Bend-Back test is a test of the propensity for cracking under extreme material strain.

Table 2: Material Requirements and Test Results

<table>
<tr><th>Test</th><th>Unit</th><th>Method</th><th>F2160-01 Requirement</th><th>F2160-16 Requirement</th><th>Test Result</th><th>Finding</th></tr>
<tr><td>Density</td><td>g/cm^3</td><td>ASTM D1505[v]</td><td colspan="2">> 0.940</td><td>0.949</td><td>PASS</td></tr>
<tr><td>Melt Index</td><td>g/10min</td><td>ASTM D1238[vi]</td><td>< 0.55</td><td>< 0.4</td><td>0.374</td><td>PASS</td></tr>
<tr><td>Flexural Modulus</td><td>psi</td><td>ASTM D790[vii]</td><td colspan="2">≥ 80,000</td><td>137,000</td><td>PASS</td></tr>
<tr><td>Tensile Yield‡</td><td>psi</td><td rowspan="2">ASTM D638[viii]</td><td colspan="2">≥ 3,000</td><td>3310</td><td>PASS</td></tr>
<tr><td>Tensile Elongation at Break‡</td><td>--</td><td colspan="2">≥ 400%</td><td>590%</td><td>PASS</td></tr>
<tr><td>Slow Crack Growth Resistance</td><td>hours</td><td>ASTM D1693[ix]
Cond. B, 10% Igepal®</td><td colspan="2">F_{10} > 96</td><td>No failures</td><td>PASS</td></tr>
</table>

‡ Die cut from conduit wall

Table 3: Conduit Dimensional and Physical Requirements and Test Results

Test	Unit	Method	F2160-01 Requirement	F2160-16 Requirement	Test Result	Finding
Outside Diameter	inch	ASTM D2122[x]	1.652 – 1.668		1.6568	**PASS**
Wall Thickness	inch	ASTM D2122	0.184 – 0.196		0.1911	**PASS**
Ovality	--	ASTM D2122	≤ 7%		4.43%	**PASS**
Stiffness†	psi	ASTM D2412	Not applicable	≥ 695	800	**PASS**
Compression & Recovery†	--	ASTM D2412[xi]	Not applicable	No cracking	No cracks	**PASS**
Low Temperature Impact Test†	--	ASTM D2444[xii] -4 °F,120 ft-lbs	No cracks		No cracks	**PASS**

†Test method requires a minimum of 3 repeat specimens to be tested. Due to specimen limitations results are based on 2 repeat specimens. The same specimens were used for Stiffness Test, Compression & Recovery test, followed by Low Temperature Impact Test.

Table 4: Non-Conduit Tests

Test	Unit	Method	Test Result
Oxidation Induction Time	Minutes	ATM D3895 200°C, Inside Surface	13.7
Bend-Back	--	ASTM D2513-01	No evidence of crazing or cracking

6.0 DISCUSSION

A visual inspection of the sample after approximately 20 years in service appears to be essentially unchanged. As shown in Figures 1 through 3, the conduit retains good color and shape[2]. The print line may have faded with time but remains legible.

There is no discernible change in the properties of the materials, as shown in Table 2. The material met and continues to meet the base material requirements of the 2001 edition standard and the essentially same requirements of the 2016 standard (the most current standard at the time of testing). Degradation of the material toughness would most likely have been apparent in a reduction in the Tensile Elongation at Break; however, the material continues to meet the minimum 400% elongation requirement indicating the material continues to have high ductility and toughness.

Although non-standard tests for conduit, the Oxidation Induction Time test and the Bend-Back test were introduced in the test program to assess whether the conduit had any propensity for cracking at the inner surface. The Oxidation Induction Time test measures the time to onset of degradation in an elevated temperature and oxygenated environment. The time to onset is the time to consumption of the residual stabilizers within the polymer matrix at the inner surface. There is no established requirement for conduit; however, the result, shown in Table 4, indicates that there is stabilizer present in the polymer matrix that will further protect the material against future oxidative aging. The Bend-Back test is a standard test for Polyethylene Gas Pipe and involves bending a sample of the wall inside out until the outer surfaces touch. As shown in Figure 4, the now highly strained and protruding inner surface is examined for signs of brittle cracking or crazing (whitening), the latter being a potential precursor to cracking. None was observed in the exhumed sample again indicating that the material remains ductile and there is no evidence of embrittlement.

After approximately 20 years, there were no significant changes in the product dimensions based on the outside diameter and wall thickness and the ovality was not significant, as shown in Table 3. The evaluated conduit also continued to meet the Low Temperature Impact requirements at -4 °F without failure. The conduit also met current day Stiffness, Compression & Recovery requirements that were not in place at the time of manufacturing.

Although the service conditions of the conduit were likely not particularly severe as it was a telecommunications conduit located in a utility vault, as compared to a direct buried or power cable conduit operating a higher temperature, it is nonetheless significant and encouraging that there are no discernible differences from 20 years in service. The conduit continues to show high ductility and evidence of stabilization from the additives originally added during production. This analysis does not provide a lifetime prediction but is strongly supportive of a long-expected service life.

[2] PPI recommends that the color yellow be reserved for gas pipe to be consistent with American Public Works Association Uniform Color Code (see Statement V - Plastics Pipe Institute Position Statement on Recommended Color Code for Solid Wall Plastic Pipe). This guidance may not have been in place at the time the tested sample was manufactured.

Figure 4: Image of Bend-Back Specimen Showing Inner Surface

7.0 CONCLUSIONS

The testing of a 20-year-old in-service ASTM F2160 HDPE conduit showed that the conduit continues to meet the original material and performance requirements from 2001 and also meets current requirements. The sample showed high toughness, no indication of embrittlement and continues to retain protective thermal stabilization.

These results are strongly supportive of a long-expected service life.

8.0 ENDNOTES

[i] ASTM F2160-01 / -16 Standard Specification for Solid Wall High Density Polyethylene (HDPE) Conduit Based on Controlled Outside Diameter (OD), ASTM International, West Conshohocken, PA, 2001 / 2016
[ii] ASTM D3350-14 Standard Specification for Polyethylene Plastics Pipe and Fittings Materials, ASTM International, West Conshohocken, PA, 2014
[iii] ASTM D3895-19 Standard Test Method for Oxidative-Induction Time of Polyolefins by Differential Scanning Calorimetry, ASTM International, West Conshohocken, PA, 2019
[iv] ASTM D2513-01 Standard Specification for Polyethylene (PE) Gas Pressure Pipe, Tubing, and Fittings, ASTM International, West Conshohocken, PA, 2001
[v] ASTM D1505-18 Standard Test Method for Density of Plastics by the Density-Gradient Technique, ASTM International, West Conshohocken, PA, 2018
[vi] ASTM D1238-20 Standard Test Method for Melt Flow Rates of Thermoplastics by Extrusion Plastometer, ASTM International, West Conshohocken, PA, 2020
[vii] ASTM D790-20 Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials, ASTM International, West Conshohocken, PA, 2017
[viii] ASTM D638-14 Standard Test Method for Tensile Properties of Plastics, ASTM International, West Conshohocken, PA, 2014
[ix] ASTM D1693-15e1 Standard Test Method for Environmental Stress-Cracking of Ethylene Plastics, , ASTM International, West Conshohocken, PA, 2015
[x] ASTM D2122-16 Standard Test Method for Determining Dimensions of Thermoplastic Pipe and Fittings, ASTM International, West Conshohocken, PA, 2016
[xi] ASTM D2412-11(2018) Standard Test Method for Determination of External Loading Characteristics of Plastic Pipe by Parallel-Plate Loading, ASTM International, West Conshohocken, PA, 2011
[xii] ASTM D2444-19 Standard Practice for Determination of the Impact Resistance of Thermoplastic Pipe and Fittings by Means of a Tup (Falling Weight), ASTM International, West Conshohocken, PA, 2019