POLYETHYLENE RESIN TESTING REQUIREMENTS TO SUPPORT ASTM D2513 UV EXPOSURE LIMITS OF POLYETHYLENE COMPOUND

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Foreword

This technical note was developed and published with the technical help and financial support of the members of the Plastics Pipe Institute (PPI). These members have shown their commitment to developing and improving quality products by assisting standards development organizations in the development of standards, and also by developing design aids and reports to help engineers, code officials, specifying groups, contractors and users.

This technical note has been prepared to provide those responsible for the maintenance of existing HDPE pipelines with suggested general guidelines for the repair of those lines that have been subjected to third party or other unforeseen damage. These guidelines constitute a set of basic operations that have been demonstrated by test and experience to produce satisfactory repairs with commercially available materials. Each specific procedure must be acceptable to, and qualified by, the operator having legal responsibility for the performance of the piping system. This document was not intended to provide system design information. Go to the PPI website at www.plasticpipe.org for different system design documents.

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1.0 INTRODUCTION

This document provides documentation and testing requirements for polyethylene (PE) materials to support the minimum UV protection requirement listed in ASTM D2513 for ASTM D3350 color and ultraviolet codes C and E. ASTM D2513 requirements for code C and E materials are:

(1) Code C material shall contain 2 to 3 percent well dispersed carbon black. Code C material is considered stabilized against deterioration from unprotected exposure to UV for not less than 10 years without the need for additional testing. Code C pipe (black PE pipe) with coextruded yellow stripe(s) is considered stabilized against deterioration from unprotected exposure to UV for not less than 10 years.

(2) Code E material is colored and shall be stabilized and protected against deterioration from unprotected UV exposure for not less than 3 years. PE compounds designated as Code E shall be considered stabilized against deterioration from unprotected exposure to UV for not less than 3 years when meeting the following criteria following exposure to actual outdoor (natural sunlight) weathering for up to 3 years in accordance with Practice D1435, or accelerated weathering in accordance with Practice D2565 and Practice G155 for the equivalent of at least 3 years natural sunlight:

   (a) all tensile bar specimens tested in accordance with Test Method D638 shall have an elongation at break value greater than 400% indicating the equivalency of the PE material before and after UV exposure against the elongation at break requirement in Specification D3350; and

   (b) all tensile bar specimens tested in accordance with Test Method D638 shall retain a minimum of 50% of their original elongation at break values. Test data shall be made available from the manufacturer upon request.

2.0 BACKGROUND

UV radiation accounts for 4.6% of the sunlight spectrum. It is measured in nanometers (nm) and ranges between 290 and 400 nm. The UV radiation energy incident over a specific area over a given period of time is called irradiation and is measured in Langley (Ly) units (1Ly = 1 cal/cm^2 = 4.184 E^{4}Joule/m^2). The amount of UV radiation exposure is dependent on one's location in the world. Example: The continuous outdoor irradiation in Sudan is approximately 220 kcal/cm^2/year while in Sweden it is 70 kcal/cm^2/year.

UV radiation from sunlight degrades plastics by breaking down the polymer chains. The physical properties that deteriorate include loss of impact strength, changes in color, cracking, loss of elongation and tensile strength as well as chalking of the surface. **Table 1** lists the UV radiation wavelengths to which plastics are sensitive. Polyethylene is sensitive between 300-310 nm, and at 340 nm.

Table 1: UV Wavelength Sensitivity of Polymers (nm)

Material	Activation spectra maxima
Polyethylene	300-310, 340
Polypropylene	290-300, 330, 370
ABS	300-310, 370-385
PVC homopolymer	320
PVC copolymer	330, 370

Photodegradation can be limited by the addition of UV stabilizers to the polymer. UV stabilizers are predominantly grouped into three categories:

(1) Ultraviolet Absorbers

UV absorbers change harmful UV radiation into harmless infrared radiation or heat that is dissipated through the polymer matrix. They are used to protect polyethylene. UV absorbers include:

- Carbon black for HDPE
- Rutile titanium oxide
- Hydroxybenzophenone
- Hydroxyphenylbenzotriazole
- Benzophenones for PVC
- Enzotriazoles and hydroxyphenyltriazines for polycarbonate
- Oxanilides for polyamides

(2) Quenchers

Quenchers transfer UV radiation to ground state through the decomposition of hydroperoxides. Nickel quenchers are common in agricultural film.

(3) Hindered Amine Light Stabilizers (HALS)

HALS are chemical compounds typically derived from tetramethylpiperidine that inhibit degradation of the polymer by continuously and cyclically removing free radicals that are produced by photo-oxidation of the polymer. HALS are regenerated rather than consumed during the stabilization process.

Carbon Black is a UV Absorber and is used in the manufacturing of HDPE pipe to prevent photodegradation. Carbon black is a fine black powder produced by partial burning and pyrolysis of low-value oil residues at high temperatures. The fundamental properties of carbon black include particle size, structure, porosity, and surface activity. The efficiency of carbon black as a UV absorber in polyethylene depends primarily on its particle size and its dispersion during the extrusion process. ASTM D2513 Code C material requires 2 to 3 percent of well dispersed carbon black in HDPE pipe. A carbon black particle size of below 25 nm is typical. Undispersed carbon black agglomerates in the pipe wall can lead to premature failure of the pressure pipe. Most of the national and international industry standards for pressure pipes recognize the importance of dispersion and specify a microscopic dispersion rating of < 3 (e.g. ISO 11420, NFT51-142).

Both UV absorbers (other than carbon black) and HALS are typically used in the manufacturing of MDPE pipe to prevent photodegradation. The mixture of absorbers and HALS can vary by resin manufacturer and is typically considered proprietary and confidential.

3.0 UV EXPOSURE TESTING

There are numerous published documents on carbon black and UV exposure protection. It is well known that due to the absorptive properties of carbon black, that PE materials utilizing at least 2.0% carbon black are considered stabilized against deterioration in excess of 20 years with some studies indicating as much as 50 years (see references 1 through 6). Therefore, no additional testing methodology was needed to support the "not less than 10-year claim" for Code C black PE pipes in D2513.

To address the Code E (colored with UV stabilizer) PE pipes, a PPI task group of industry experts was formed. This task group collected testing methodology from several PE resin companies that produce grades used for the Code E PE pressure pipe production, reviewed industry practices and several technical documents.

UV exposure only affects the surface layer of a plastic pipe. The compound inside the pipe wall is protected by the surface layer. Pipe that is not sufficiently UV stabilized may undergo molecular chain degradation from UV exposure. As a result, PE materials may lose toughness and become brittle or become more susceptible to slow crack growth failure. Elongation at break is a very sensitive parameter to molecular weight and molecular degradation. ASTM D638 tensile strength at yield and elongation at break testing are effective means to evaluate the effects of UV exposure.

UV exposure can be accomplished via artificial and natural means. Howard and Gilroy at Bell Telephone Laboratories published a paper in 1969 that covered natural and artificial UV testing of PE. This paper also included information on various carbon black sizes and the resultant PE UV resistance. It was determined that for artificial exposure, testing in a weatherometer in accordance with ASTM D2565 (cycle 2 with daylight filters) and ASTM G155 (with intermittent spray with irradiance of 0.35 $W/m^2/nm$ at 340 nm wavelength and 63 °C) was appropriate and widely used. A paper published at Eurotec 2011 on UV rating methods for injection molding PE grades concluded that the Xenon Arc method for accelerated UV testing gave the best correlation with outdoor exposure testing.

There are numerous methods to test UV resistance, which include outdoor exposure and accelerated laboratory testing methods. Most test methods include exposing tensile bars to a UV source and then performing ASTM D638 tensile testing at specified intervals of UV exposure (typically at 1,000-hour increments). Tensile testing is usually performed on two types of PE tensile bars – Type IV and Type V. For reference, Type IV tensile bars have dimensions of 115 mm (4.5”) minimum length, 19 mm (0.75”) minimum width and a thickness of 3.2 ± 0.4 mm (0.13 ± 0.02”). Type V tensile bars have dimensions of 63.5 mm (2.5”) minimum length, 9.53 mm (0.375”) minimum width and the same thickness as Type IV bars. Both bar types are referenced in ASTM D638. A bar thickness of 3.2 ± 0.4 mm (0.13 ± 0.02”) would correspond to ASTM D2513 pipes sizes of at least IPS 1 or CTS 1 DR11.

Publications show various UV radiance levels throughout the world and published equations may be used to calculate the projected lifetime of a PE product based on the desired UV rating of the material and annual solar radiation for a geographical area. Studies have shown that HDPE exposed to Xenon Arc yields approximately 4.4 times the acceleration of outdoor exposure in Florida (Ratzlaff, 2011). Therefore, around 2000 hours Xenon Arc testing would equal about 1-year outdoor exposure in Florida. Other geographical areas such as Southern California would have a correlation of about 1250 hr exposure to Xenon Arc equaling about 1-year outdoor exposure and Southern Canada would have a correlation of about 1000 hrs Xenon Arc exposure equaling about 1-year outdoor exposure.

PE industry applications use pass/fail criteria for a material or compound as 50% retention of the initial tensile elongation at break after 3000 to 6000 hours of UV exposure (ExxonMobil, 2003). Also, ASTM D3350 requires a minimum of 400% elongation at break for the compound before UV exposure.

4.0 CONCLUSIONS

Based upon industry published studies on the UV protection provided by carbon black, the PPI task group concluded that ASTM D2513 Code C pipes were stabilized for at least 10 years exposure and that no further testing was needed. The PPI task group concluded that for artificial UV exposure ASTM D638 tensile bars for Code E yellow pipe PE grades should be UV exposed per ASTM D2565 (Cycle 2 with daylight filters) along with ASTM G155 (with intermittent spray for an irradiance of 0.35 W/m^2/nm at 340 nm wavelength at 63 °C). The UV exposed (by accelerated Xenon Arc or outdoor exposure) tensile bars should have a minimum 50% retained elongation at break and retain the applicable ASTM D3350 tensile strength at yield of the original compound cell classification. It is proposed that such a testing methodology would demonstrate performance for the requirements of ASTM D2513 outdoor storage stability for Code E grades.

5.0 REFERENCES & STANDARDS

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12) Craftech Industries, Inc.; *The Top 3 Plastic Additives for UV Stabilization*; https://www.craftechind.com/uv-radiation/.
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6.0 UV LIGHT EXPOSURE STANDARDS

ASTM G151 - *Standard Practice for Exposing Nonmetallic Materials in Accelerated Test Devices that Use Laboratory Light Sources*

ASTM G154 - *Standard Practice for Operating Fluorescent Ultraviolet (UV) Lamp Apparatus for Exposure of Nonmetallic Materials*

ASTM G155 - *Standard Practice for Operating Xenon Arc Lamp Apparatus for Exposure of Materials*

ASTM D4329 - *Standard Practice for Fluorescent Ultraviolet (UV) Lamp Apparatus Exposure of Plastics*

ISO 4892-1 - *Plastics -- Methods of Exposure to Laboratory Light Sources -- Part 1: General Guidance*

ISO 4892-2 - *Plastics - Methods of Exposure to Laboratory Light Sources - Part 2: Xenon-Arc Lamps*

ISO 4892-3 – *Plastics – Methods of Exposure to Laboratory Light Sources – Part 3: Fluorescent UV Lamps*

ISO 4892-4 - *Plastics - Methods of Exposure to Laboratory Light Sources - Part 4: Open-Flame Carbon-Arc Lamps*