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Rate Process Method for Projecting Performance of Polyethylene Piping Components TN-16/2008

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Foreword

This report was developed and published with the technical help and financial support of the members of the PPI (Plastics Pipe Institute, Inc). The members have shown their interest in quality products by assisting independent standards-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.

The purpose of this technical note is to provide general information on use of an industry-accepted method (Rate Process Method) to evaluate performance of polyethylene pipe and fittings.

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RATE PROCESS METHOD FOR PROJECTING PERFORMANCE OF POLYETHYLENE PIPING COMPONENTS

1.0 Introduction

The PPI Hydrostatic Stress Board (HSB) conducted an extensive evaluation of various methods for forecasting the effective long-term performance of polyethylene (PE) thermoplastic piping materials. Basically, these methods require elevated temperature sustained pressure testing of pipe where the type of failure is of the slit or brittle-like mode. Details of this evaluation and conclusions are contained in reference 1.

As a result of this study, HSB determined that the three-coefficient rate process method (RPM) equation provided the best correlation between calculated long-term performance projections and known field performance of several PE piping materials. It also had the best probability for extrapolation of data based on the statistical “lack of fit” test.

The Rate Process Method (RPM), which was developed out of this study, was incorporated in two ASTM standards. ASTM D 2837 (2) added a “validation” requirement for PE piping materials, and ASTM D 2513 (3) added a validation requirement for the pipe producer. Since some high performance PE materials do not exhibit SCG (slit or brittle-like failure) under elevated temperature testing, the RPM method can not be applied to these materials for the established validation methods. The ASTM standard test method for determining chlorine resistance of PEX tubing, ASTM F 2023 (4), uses the Rate Process Method for its projected performance calculations.

Provided that the RPM method is applied to materials that demonstrate SCG (slit or brittle-like failure) resin and pipe producers, as well as end-users, may apply RPM calculations to make relative judgments on specific materials and/or piping products. One example has been to use the RPM to estimate projected life of SCG-susceptible PE pipe exhumed from buried service. Projections from the Rate Process Method for this exhumed PE gas pipe were shown to have very good correlation with actual field failures from three gas companies (5). These projections are based on the primary load, which is the internal pressure. RPM can also be used to determine the effects of secondary loads such as indentation (rock impingement), bending, deflection or squeeze-off.

Another example is projected performance of polyethylene fittings as discussed in references 6 and 7. Because fittings have different geometries, different failure modes may be observed at different test conditions. The three RPM coefficients from each fitting will be different; again, this is due to their different geometries.

The referenced paper by Bragaw (6) shows different Arrhenius plot slopes (log t vs. 1/T) for the different fittings tested, indicating different coefficients. This RPM test protocol is not intended for mechanical fittings.

Single-point elevated temperature stress rupture testing is used for quality control testing of PE piping products once RPM data are available, as discussed in reference 8.

More recently, the Rate Process Method has been used to determine long-term performance of corrugated PE pipe and the effect of recycled materials on long-term performance (9).

In addition, the RPM has been applied to a notched constant load specimen test to forecast the slow crack growth resistance of corrugated HDPE pipes (10).

PPI is publishing this Technical Note covering the recommended RPM procedure to offer guidance and a degree of standardization to the evaluation of PE piping components using elevated temperature sustained pressure testing.

A number of state-of-the-art PE resins, when properly extruded into pipe, will not exhibit slit mode failures in reasonable test times even when tested at the maximum temperature. Therefore, the RPM procedure is not applicable for these materials except as a qualifying procedure to ensure, in fact, slit mode failures do not occur.

2.0 Test Procedure

Testing of pipe assemblies shall be in accordance with ASTM D 1598 (11). Fittings are joined to pipe using standard heat fusion joining procedures, such as butt fusion, socket fusion, saddle fusion or electrofusion. This RPM test procedure is not intended for mechanical fittings. Other test configurations such as notched constant load specimens (NCLS) per ASTM F 2136 or PENT per ASTM F 1473 can be used as well.

3.0 Test Conditions

3.1 **Temperatures**. Select two or three elevated temperatures appropriate for the PE material (T_1, T_2, T_3). The maximum temperature chosen should not be greater than 95°C. Typical temperatures selected for PE pipes are 80 and 60ºC when two temperatures are used, and 90, 80 and 70°C for three temperatures. The minimum temperature difference should be 10ºC for three temperatures, and 20ºC for two temperatures.

3.2 **Stress.** If a selected hoop stress results in a ductile failure, the stress should be lowered. Stresses selected should be such as to produce only slit mode failures. There should be a 10 percent minimum difference between selected stresses. Also, there should be a minimum of three specimens at each selected stress if three temperatures are used as in Table I. If only two temperatures are used, the minimum specimens at each stress should be four as in Table II.

TABLE I (THREE TEMPERATURES)

Temperature	T_1	T_2	T_3
Number of hoop stresses	3	2	1
Number of specimens	9	6	3

TABLE II (TWO TEMPERATURES)

Temperature	T_1	T_2
Number of hoop stresses	3	2
Number of specimens	12	8

Therefore, to do a typical RPM experiment would require a minimum of 18 specimens for three temperatures, or a minimum of 20 specimens for two temperatures. An RPM calculation can be made with fewer specimens, but the confidence in the projection decreases as the number of specimens decreases. If one wants to test more specimens, we recommend testing more specimens at each hoop stress, followed by more hoop stresses at each temperature, and lastly, more temperatures.

4.0 Calculations

Using all the slit failure mode data points, calculate the A, B and C coefficients for the following three-coefficient rate process method extrapolation equation:

$$\mathit{Log}\ t = A + \frac{B}{T} + \frac{C \operatorname{Log} S}{T}$$

Where:

t = slit mode failure time, hours
T = absolute temperature, K
S = hoop stress, psi or pressure, psig

When testing and evaluating pipe and fittings it is very important that all the failure modes be the same (i.e. either ductile or brittle). When applying the RPM calculation all failure modes must be the same.

Example

Here are stress rupture data for a polyethylene pipe lot obtained at two temperatures. All these data have the slit failure mode:

Temp. (ºC)	Stress (psi)	Failure time (hours)
80.	600.	30.0
80.	600.	32.0
80.	600.	23.0
80.	600.	19.0
80.	600.	27.0
80.	600.	22.0
80.	300.	280.0
80.	300.	222.0
80.	300.	198.0
80.	300.	379.0
80.	300.	194.0
80.	300.	243.0
80.	175.	728.0
80.	175.	1413.0
80.	175.	1485.0
80.	175.	985.0
80.	175.	1548.0
80.	175.	996.0
60.	600.	207.0
60.	600.	163.0
60.	600.	390.0
60.	600.	547.0
60.	600.	416.0
60.	600.	130.0
60.	300.	3472.0
60.	300.	3198.0
60.	300.	2672.0
60.	300.	3936.0
60.	300.	2790.0

The three coefficients for the RPM equation are:

A = -16.241
B = 9342.2
C = -1120.4

5.0 Application

5.1 Once the A, B and C coefficients are calculated, the RPM equation can be used for various performance projections. For the above example, at an average ground temperature of 20ºC (68ºF) and an average hoop stress of 300 psi (60 psig for SDR 11 pipe), the mean projected failure time is 165 years. Some RPM calculations can also include a lower confidence limit (LCL) by using the distribution of the data points. In this case the 5% LCL is 65 years. This means there is 95% probability that the pipe failure time will be greater than 65 years.

5.2 Mathematically, these RPM projections are sound. However, they are not absolute and are subject to various experimental errors, unknown deviations and judgment factors.

5.3 Calculations from the RPM equation should be used in conjunction with all other mechanical, performance, and use factors in making judgments as to design, useful life or application suitability. When mixed ductile-SCG failures are observed or where SCG failures do not occur, RPM may not be used.

6.0 References

1. “Rate Process Concepts Applied to Hydrostatically Rating Polyethylene,” by E. F. Palermo and I. K. DeBlieu, presented at the Ninth Plastic Fuel Gas Pipe Symposium, 1985, in New Orleans, Louisiana

2. ASTM D 2837, “Standard Test Method for Obtaining Hydrostatic Design Basis for Thermoplastic Pipe Materials”

3. ASTM D2513, “Standard Specification for Thermoplastic Gas Pressure Pipe, Tubing, and Fittings”

4. ASTM F2023, “Standard Test Method for Evaluating the Oxidative Resistance of Crosslinked Polyethylene (PEX) Tubing and Systems to Hot Chlorinated Water”,

5. “Correlating Aldyl “A” and Century PE Pipe Rate Process Method Projections With

Actual Field Performance" by E.F. Palermo (Jana Laboratories), presented at the 2004 AGA Operations Conference.

6. "Prediction of Service Life of Polyethylene Gas Piping Systems" by C. G. Bragaw, presented at the Seventh Plastic Fuel Gas Pipe Symposium, 1980, in New Orleans, Louisiana

7. "Rate Process Method Applied to Service Life Forecast of PE Molded Fittings" by E. F. Palermo and S. Chung, presented at the 2008 AGA Operations Conference

8. "Rate Process Method as a Practical Approach to a Quality Control Method for Polyethylene Pipe" by E. F. Palermo, presented at the Eighth Plastic Fuel Gas Pipe Symposium, 1983, in New Orleans, Louisiana

9. "New Test Method to Determine the Effect of Recycled Materials on the Life of Corrugated HDPE Pipe as Projected by the Rate Process Method", E. F Palermo and K. Oliphant (Jana Laboratories), presented at Plastics Pipes XIII, October 2006, in Washington, DC

10. "Evaluate the Long-Term Stress Crack Resistance of Corrugated HDPE Pipes", Y. Grace Hsuan, J-Y Zhang and W-K Wong, Department of Civil, Architectural and Environmental Engineering, Drexel University, Philadelphia, USA

11. ASTM D 1598, "Standard Test Method for Time-to-Failure of Plastic Pipe Under Constant Internal Pressure"