JP 916

JANA MODE 3 SHIFT FUNCTIONS

Alternate Test Methodology for Assessing PE Compound Performance in Potable Water Applications

March 2012

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Executive Summary

A new methodology has been developed to assess the performance of polyethylene piping materials in potable water applications. The methodology is the result of several connected research programs undertaken to both develop and validate a model capable of estimating performance of PE pipe in potable water applications[1,2].

The methodology is based on testing specimens in accordance with the testing approach developed in ASTM F2263[3] to determine the long-term performance capabilities at end-use conditions. Testing is conducted at a single elevated temperature condition followed by application of the Jana Mode 3 Shift Functions and a Stress Shift Function to project performance at a specific end-use temperature and stress. The resulting projections are seen to be in good agreement with those projected from full ASTM F2263 testing and, hence, provide an alternate approach for projecting PE pipe compound performance in potable water applications. The approach is also well suited for use in developing minimum performance validation criteria.

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New Methodology for Assessing Performance of HDPE Potable Water Piping

A new methodology has been developed to assess the performance of polyethylene piping materials in potable water applications. The methodology is the result of several connected research programs undertaken to both develop and validate a model capable of estimating performance of PE pipe in potable water applications.

Basis of Methodology

The methodology is based on testing in general accordance with the ASTM F2263[3] test standard at a single accelerated test condition, and then using the Jana Mode 3 Shift Functions to estimate performance under end-use conditions, analogous to the shift function approach used for validation of PE Stage II performance. A second stress shift is also applied to adjust the projections to the specific end-use operating stress (pressure). Overall, then, it is possible to test at a single elevated test condition and make projections of PE pipe compound performance at end-use conditions.

Shift Function Approach

The basis for the Shift Function approach is the application of the Jana Mode 3 Shift Functions developed specifically for the long-term aging mechanism (Mode 3)[1] for PE pipe materials in potable water applications. A Stress Shift Factor is also applied so that accelerated testing will generate the correct long-term aging mechanism. For both of these, the modeling constants were empirically derived based on analysis of available ASTM F2263 data. While these general approaches have been applied to validation of plastic pipe performance previously, this is their first application to validation of the Mode 3 aging mechanism for PE pipe materials. The development and basis for the Shift Functions are, therefore, discussed in the sections that follow.

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Jana Mode 3 Bi-Directional Shift Functions

Bi-directional shift functions were developed for the Mode 3 long-term aging mechanism based on the general shift functions proposed by Brown and Lu[4]:

$$t_f(T_1) = t_f(T_2) \cdot e^{Q_1/R \cdot (1/T_1 - 1/T_2)} \quad (1)$$

and

$$\sigma(T_1) = \sigma(T_2) \cdot e^{Q_2/R \cdot (1/T_1 - 1/T_2)} \quad (2)$$

where

Q_1 = the activation energy for the temperature shift (J/mol)
Q_2 = the activation energy for the stress shift (J/mol)
R = gas constant (J/mol·K)
t_f = time to failure (h)
T = temperature (K)
σ = hoop stress (psi)

Based on the currently available data, a new set of bi-directional shift functions was empirically derived for the Mode 3 aging mechanism. The basic bi-directional shift functions of Brown and Lu were utilized with Q_1 = 55 kJ/mol and Q_2 = 10.5 kJ/mol. For the Mode 3 aging mechanism, a similar stress dependence but significantly different temperature dependence is observed for Stage II in the modeling of Brown[4] and Popelar[5]. It is postulated that this is due to specific Mode 3 mechanism and the interplay between degradation and stress in the time to crack initiation. The resultant shifts and their comparison with RPM projections are presented in **Figures 1 through 6**.

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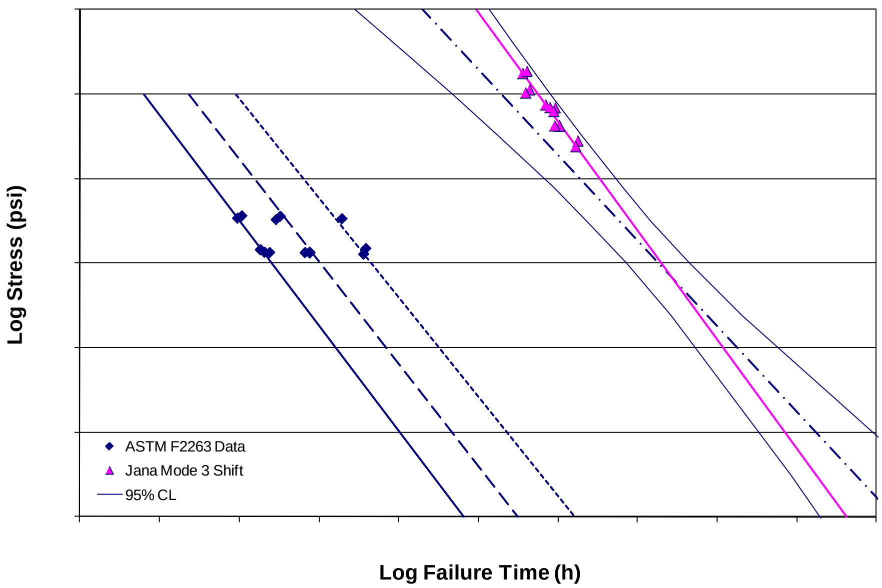
Figure 1: Dataset 1



NOTES:

- Data generated in general accordance with ASTM F2263.
- 95% Confidence Limits for the ASTM F2263 data also shown.
- Jana Mode 3 Shift calculations based on the basic bi-directional shift functions of Brown and Lu with Q_1 = 55 kJ/mol and Q_2 = 10.5 kJ/mol.

Figure 2: Dataset 2

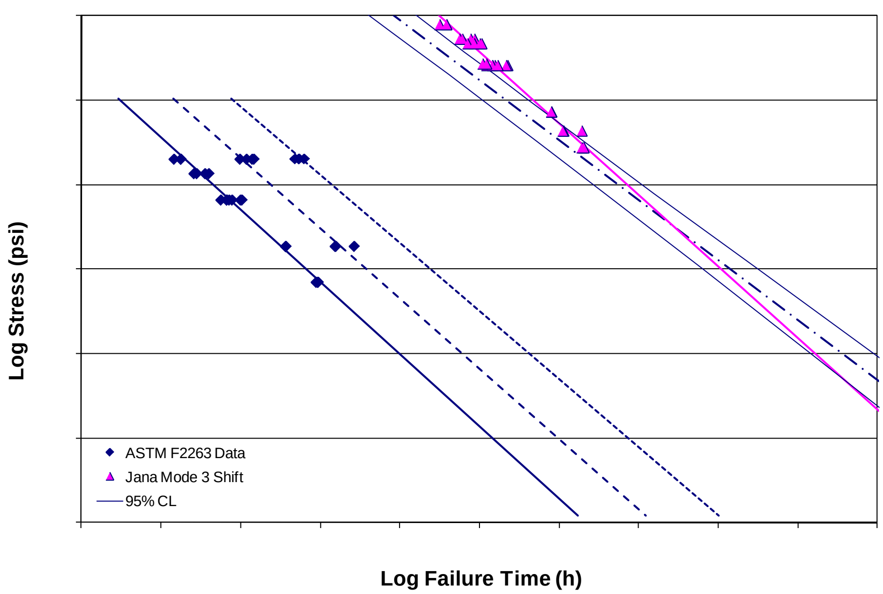


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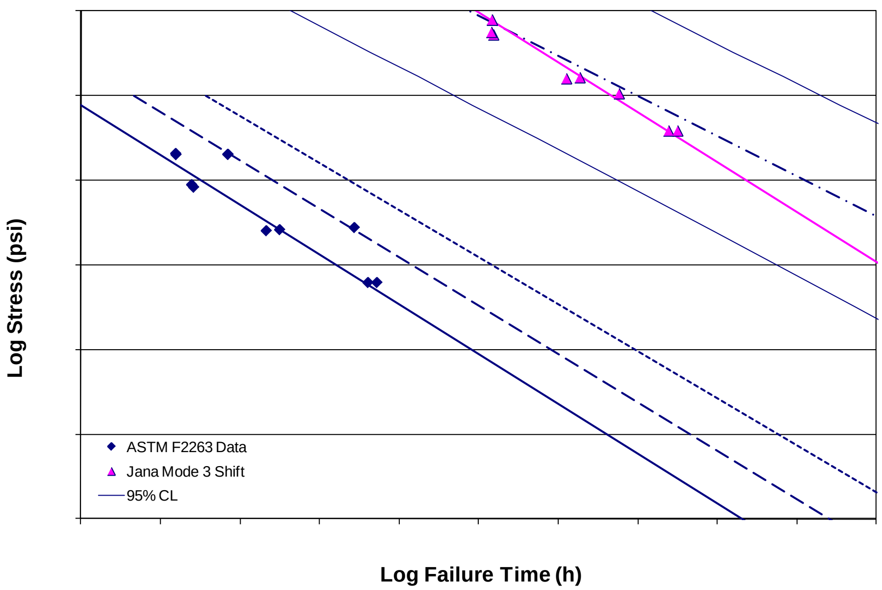
Figure 3: Dataset 3



NOTES:

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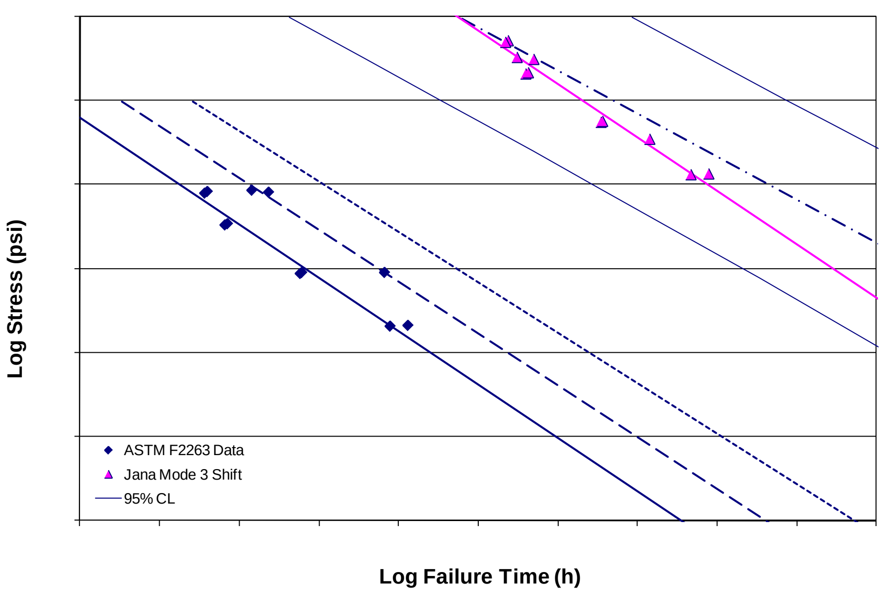
- Jana Mode 3 Shift calculations based on the basic bi-directional shift functions of Brown and Lu with Q_1 = 55 kJ/mol and Q_2 = 10.5 kJ/mol.

Figure 4: Dataset 4



NOTES:

- Data generated in general accordance with ASTM F2263.
- 95% Confidence Limits for the ASTM F2263 data also shown.
- Jana Mode 3 Shift calculations based on the basic bi-directional shift functions of Brown and Lu with Q_1 = 55 kJ/mol and Q_2 = 10.5 kJ/mol.

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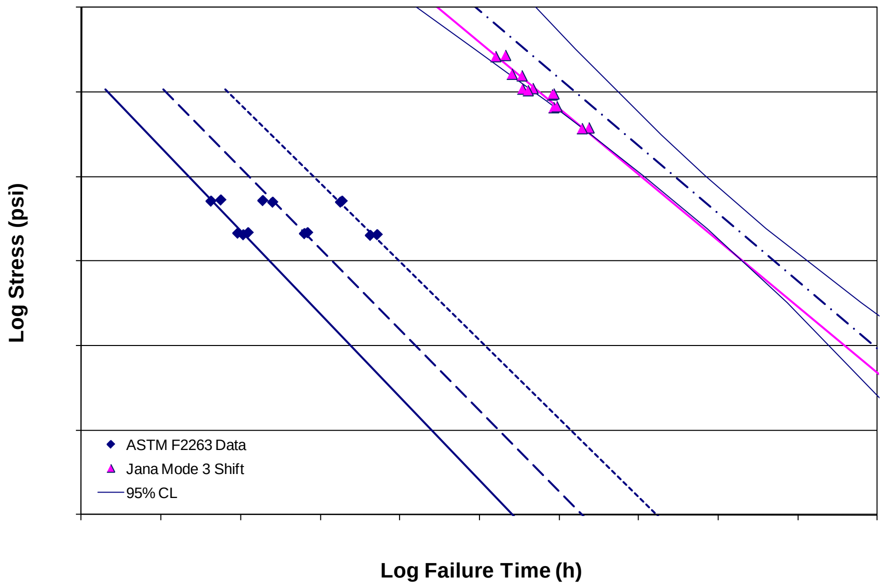
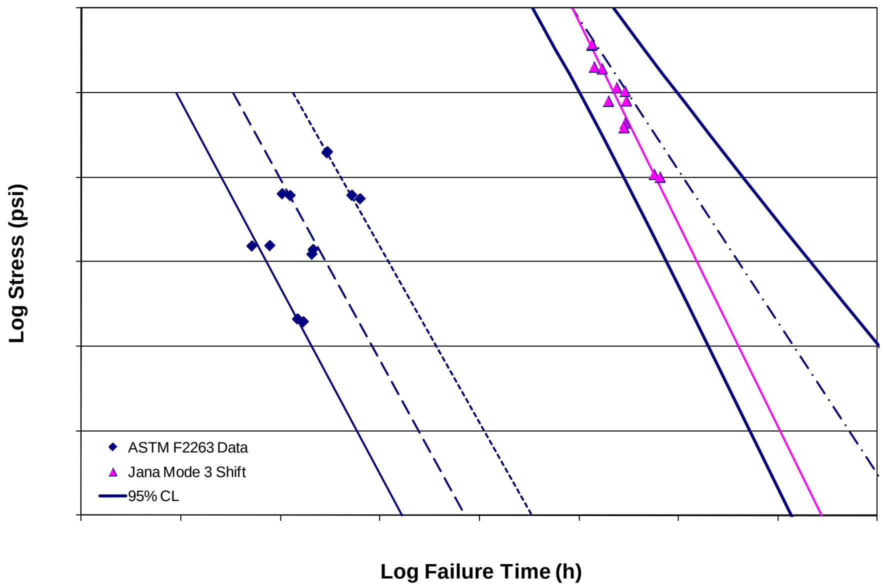
Figure 5: Dataset 5



NOTES:

- Data generated in general accordance with ASTM F2263.
- 95% Confidence Limits for the ASTM F2263 data also shown.
- Jana Mode 3 Shift calculations based on the basic bi-directional shift functions of Brown and Lu with Q_1 = 55 kJ/mol and Q_2 = 10.5 kJ/mol.

Figure 6: Dataset 6



NOTES:

- Data generated in general accordance with ASTM F2263.
- 95% Confidence Limits for the ASTM F2263 data also shown.
- Jana Mode 3 Shift calculations based on the basic bi-directional shift functions of Brown and Lu with Q_1 = 55 kJ/mol and Q_2 = 10.5 kJ/mol.

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Within the confidence limits of the RPM projections, good correlation between the RPM projections based on ASTM F2263 testing and the application of the Jana Mode 3 Shift Functions to the test data is observed. This general correspondence is observed for all the ASTM F2263 datasets generated to date. The model is, therefore, capable of providing an alternative approach to full ASTM F2263 testing, allowing testing at a single elevated test condition followed by shifting the resultant test time from the test temperature to the end-use temperature. This is analogous to the approach successfully used for validation of Stage II performance for PE piping materials developed by Popelar[5].

Stress Shift

In order to the adjust this shifted time and the end-use temperature to the end-use stress, a stress function for Mode 3 stress dependence was developed based on[4]:

$$t_f \propto \sigma^{-n} \qquad (3)$$

where

$n = 3.5$ was empirically determined based on available test data
t_f = time to failure (h)
σ = hoop stress (psi)

Testing can, then, be conducted at a single elevated test temperature and, through application of the Mode 3 Jana Shift Functions and Stress Shift Function, performance at a specific end-use temperature and stress condition can be projected. The resultant projections are seen to be in good agreement with those obtained through the current ASTM F2263 test methodology, providing an approach that could potentially be used to develop minimum performance validation criteria.

Summary

A new methodology has been developed for assessing the performance of PE piping materials in potable water applications based on multiple connected research programs carried out over the past several years. The methodology involves testing at a single elevated temperature condition and application of the Jana Mode 3 Shift Functions and a Stress Shift Function to project performance at a specific end-use temperature and stress. The resulting projections are seen to be in good agreement with those projected from full ASTM F2263 and, hence, provide an alternate approach for projecting PE pipe compound performance in potable water applications that is well suited for use as the basis for development of minimum performance validation criteria.

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References

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4. Lu, X. and Brown, N., *Polymer*, 1997, **38**, 5749.

5. Kenner, V.H., Popelar, C.H. and Wooster, J.P., *12th Plastic Fuel Gas Pipe Symposium*, 1991, p. 130.

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