Assessment of Squeeze-off Location for Small Diameter Polyethylene (PE) Pipe and Tubing

Oren Lever, Ernest Lever
Gas Technology Institute
1700 S. Mount Prospect Road, Des Plaines, IL 60018 USA
oren.lever@gastechnology.org, ernest.lever@gastechnology.org

Abstract: A pipe squeeze-off model with a custom viscoelastic-plastic constitutive model for PE was created in COMSOL Multiphysics to simulate the very large deformations involved in pipe squeeze-off. Squeeze-off of small diameter pipes was simulated and the results indicated that squeeze-offs at a distance of three pipe diameters, but less than 12 inches, from a fused coupling did not produce strains that exceed industry accepted levels.

Keywords: Polyethylene, pipe, squeeze-off, large deformations, viscoelastic-plastic

1. Introduction

Squeeze-off of PE pipe (Figure 1) is a common method that is used to stop gas flow to enable downstream repairs or perform emergency shutoff. Current ASTM standard F1041-02(2008) details how to perform squeeze-offs for this material. Article 7.3 of this standard states squeeze-off must be performed "at least three (3) pipe diameters or twelve (12)-inches (305 mm), whichever is greater, from any fusion joint (1.5 diameters for butt-fusion joint) or mechanical fitting". This standard is widely adhered to within the gas industry.

Several natural gas utilities have expressed interest in examining the potential for reducing current minimum squeeze-off distances for small pipe diameters (<=3" IPS), where the current minimum of 12-inches is larger than three (3) pipe diameters. Reducing the minimum allowable distance from a fitting will help facilitate routine operations and maintenance (O&M) tasks.

A project was set up at GTI[1] to study the impact of a reduction in minimum squeeze-off distance, sponsored by Operations Technology Development[2] (OTD). Finite Element Analysis (FEA) and accelerated testing were performed to provide a solid standing for any proposed changes to the best-practices outlined in ASTM F1041-02(2008).

Figure 1. Squeeze-off of PE pipe

2. Use of COMSOL Multiphysics

GTI developed a fully parametric, time-dependent PE squeeze-off model in COMSOL Mulitphysics, utilizing the Nonlinear Structural Materials Module and a custom viscoelastic-plastic constitutive model developed specifically for PE by Veryst Engineering[3].

The model utilizes a contact pair to simulate the internal pipe-to-pipe contact, and a contact pair between the squeeze-bar and pipe to get correct deformation of the pipe (Figure 2). The simulation sequence followed the operation sequence and covered pressurization of the pipe, squeeze-off, hold, release, and subsequent pipe relaxation (Figure 3).

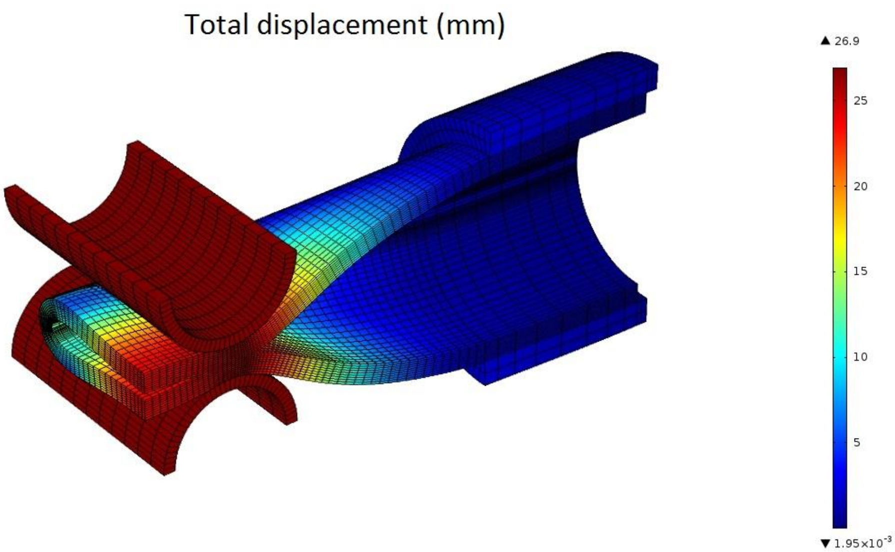

Figure 2. COMSOL Multiphysics simulation of PE pipe squeeze-off

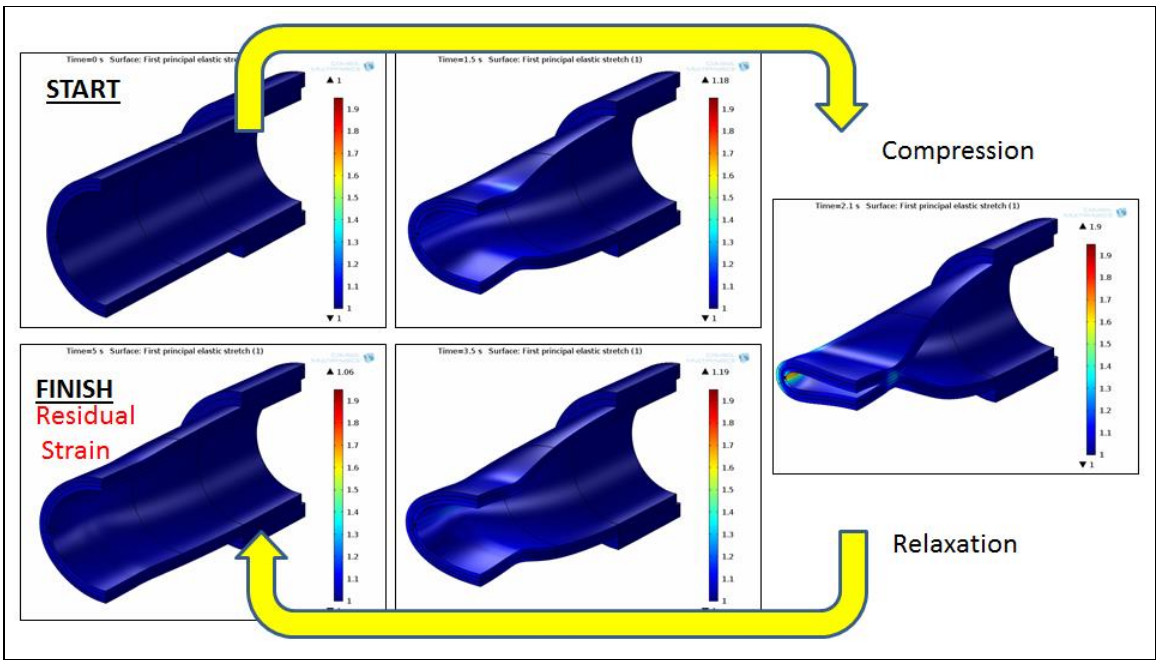

Figure 3. Pipe squeeze-off simulation sequence

Special attention had to be given to the meshing of the pipe which, together with the custom constitutive model, enabled the simulation of the very large deformations encountered in pipe squeeze-off (Figure 4).

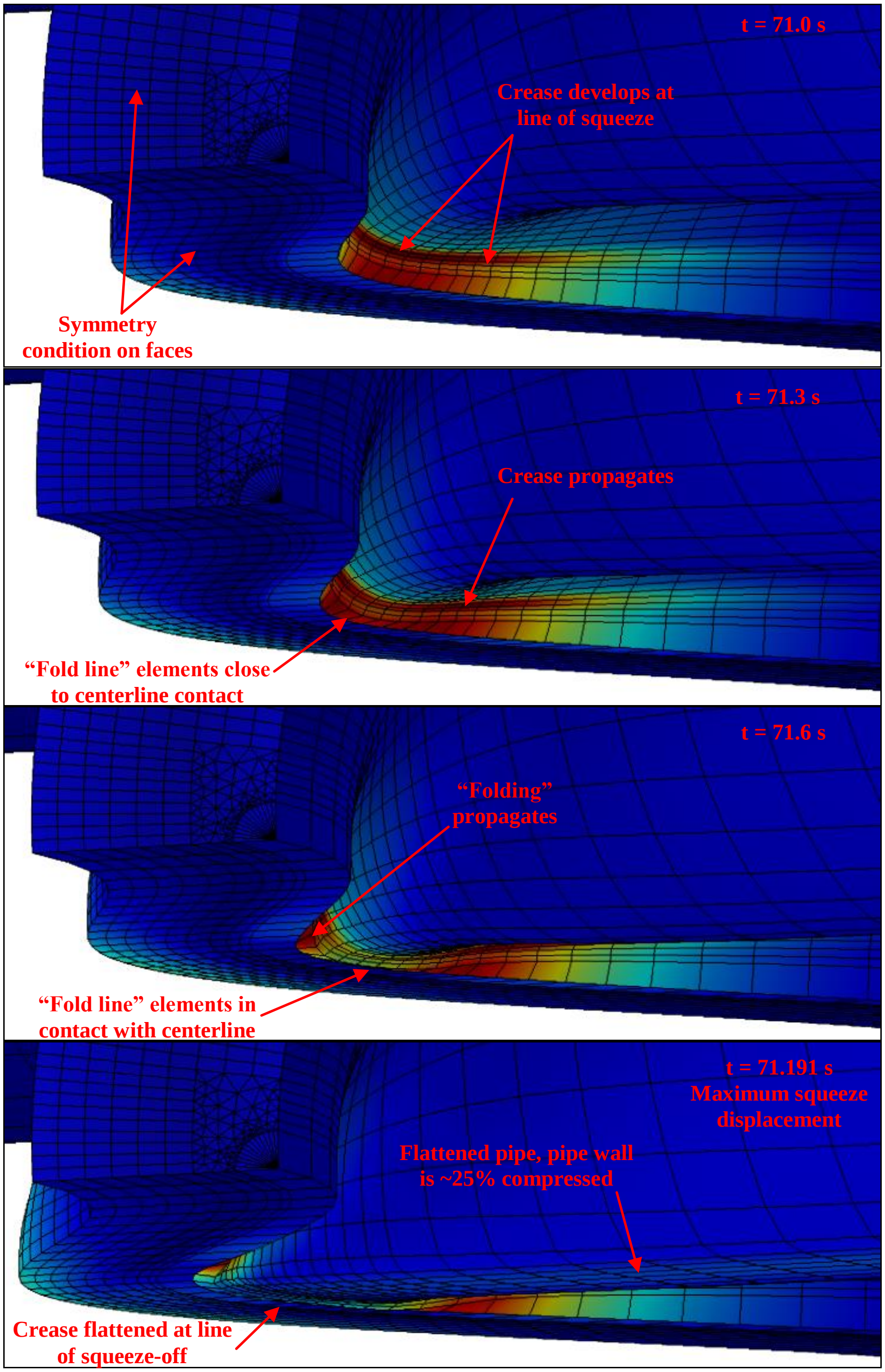

Figure 4. Deformation at line of squeeze-off, just before and at maximum squeeze displacement

3. Constitutive Model and Equations

The squeeze-off simulation made use of COMSOL's Nonlinear Structural Mechanics Module and a custom viscoelastic-plastic network model (Figure 5) using the Ordinary Differential Equation (ODE) functionality of COMSOL. The model was developed in order to capture the highly nonlinear mechanical response of PE, including at very large strains. An example of the tensile response of PE and the model fit is shown in (Figure 6). For details on the PE network model please see Reference 3.

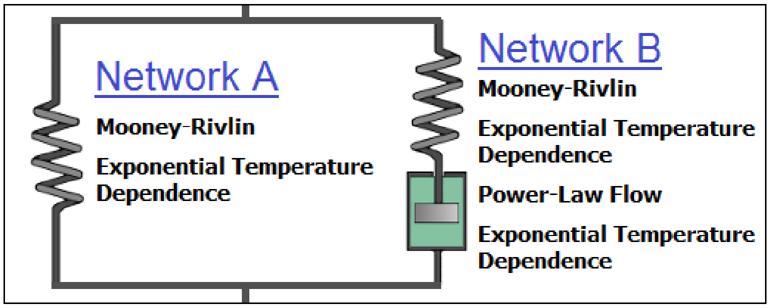

Figure 5. Constitutive model used in PE pipe squeeze-off model

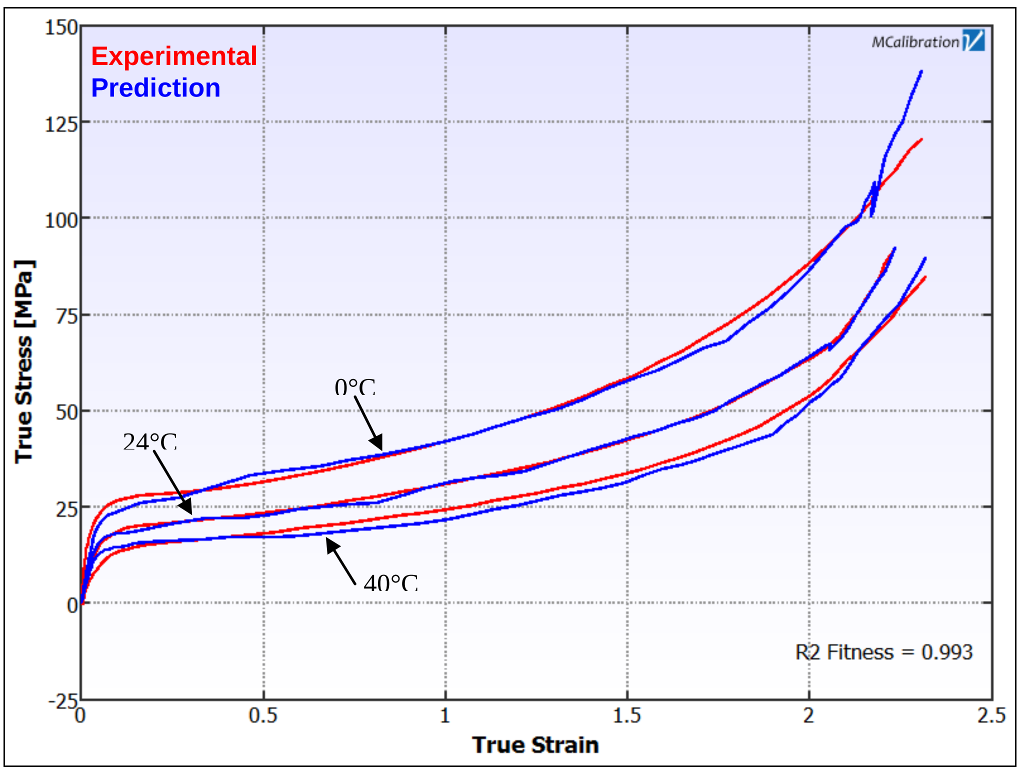

Figure 6. Example of the network model capturing large tensile strains, at different temperatures

4. Material Testing

To calibrate the constitutive model, GTI carried out a comprehensive material testing program covering mechanical responses up to very large strains in tension and compression, at various strain-rates, and at various temperatures. Special care was taken to get the true stress-strain response at large deformations (Figure 7), which necessitated the use of a video extensometer. Stress relaxation tests in tension and compression were also performed at various temperatures and strain levels.

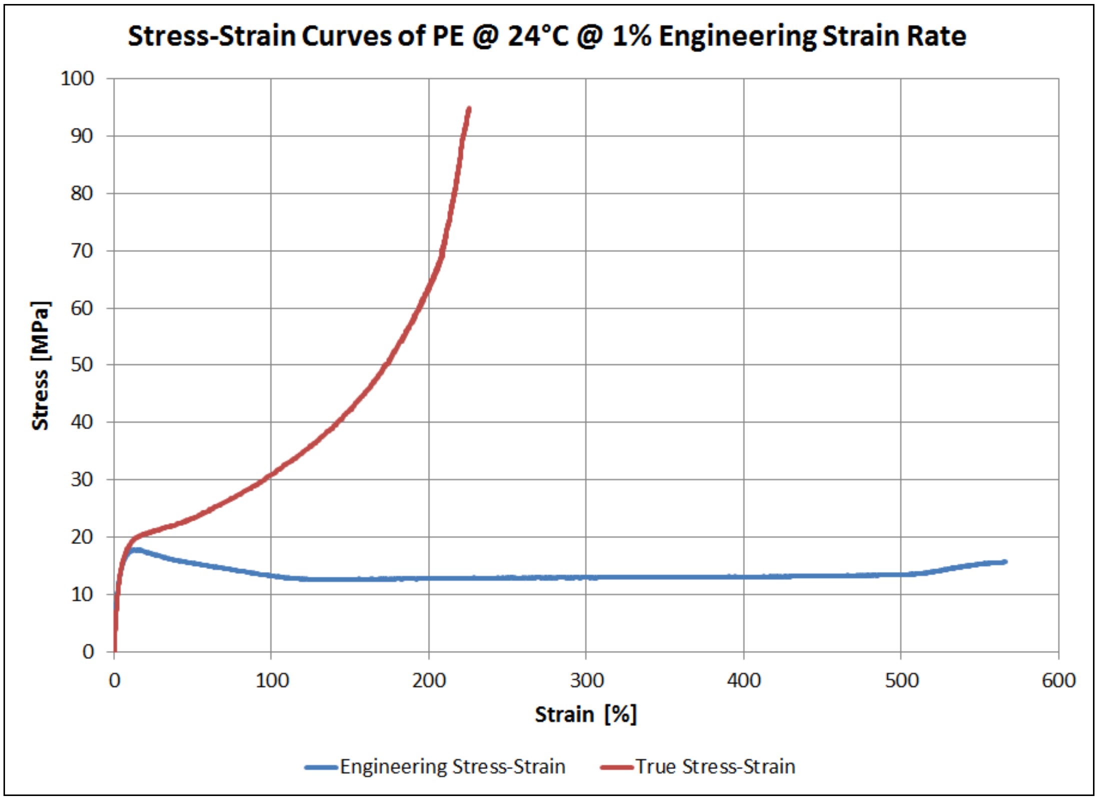

Figure 7. Engineering and True stress-strain curves of PE

5. Simulation Results

The simulation results are shown in (Table 1). The results indicate that squeeze-offs of small diameter pipe performed at distances of three (3) pipe diameters from a fused coupling, do not induce strains larger than industry accepted strains for bent pipe. Accepted bending radii for PE pipe are shown in (Table 2), and (Figure 8) shows the formula used for calculating the maximum strain at each bend radius.

Table 1: Maximum First Principal strain at vicinity of coupling edge, per geometric configuration

Pipe Configuration	1/2" IPS DR11	1/2" IPS DR11	1/2" IPS DR11	2" IPS DR11	2" IPS DR11	2" IPS DR17.6	4" IPS DR11	6" IPS DR11
Offset	12-inch	3xOD	2.5xOD	12-inch	3xOD	2.5xOD	3xOD	3xOD
Distance [in]	4.800	3.175	3.087	7.320	4.703	10.272	16.605	23.453
Pipe Strain [%]	0.38	0.92	1.06	1.19	1.26	1.46	2.17	3.12
Coupling Strain [%]	0.40	1.26	1.47	0.61	0.66	1.73	1.23	1.18

Table 2: Outer diameter (OD) multipliers for minimum pipe bend radius[4] and resulting maximum nominal bend strain

Pipe Dimension Ratio (DR)	Pipe Bend Radius	Max Strain [%]
7, 7.3 , 9	20 x Pipe OD	2.50
11, 13.5	25 x Pipe OD	2.00
17, 21	27 x Pipe OD	1.85
26	34 x Pipe OD	1.47
32.5	42 x Pipe OD	1.19
41	52 x Pipe OD	0.96
Fitting	100 x Pipe OD	0.50
DR = (Pipe OD) / (Pipe Wall Thickness)		

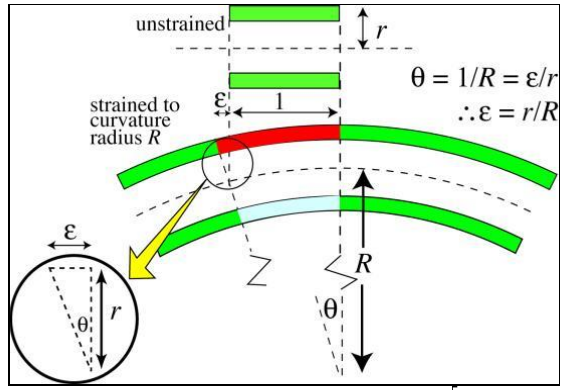

Figure 8. Pipe bending strain formula[5]

6. Accelerated Hydrostatic Testing

To verify the simulation's findings, accelerated lifetime tests were initiated for 1" CTS (0.63-inch OD) pipes squeezed off at a distance of two (2) and four (4) inches from a fused coupling. The hydrostatic tests were performed at temperatures of 60°C, 80°C, and 90°C, which greatly accelerate the creep rate of the polymer versus normal operating conditions (~20°C). To date, the samples have logged between 1100 and 4800 hours under tests, which translated to over 80 years of service at 20°C (design lifetime is 80 years).

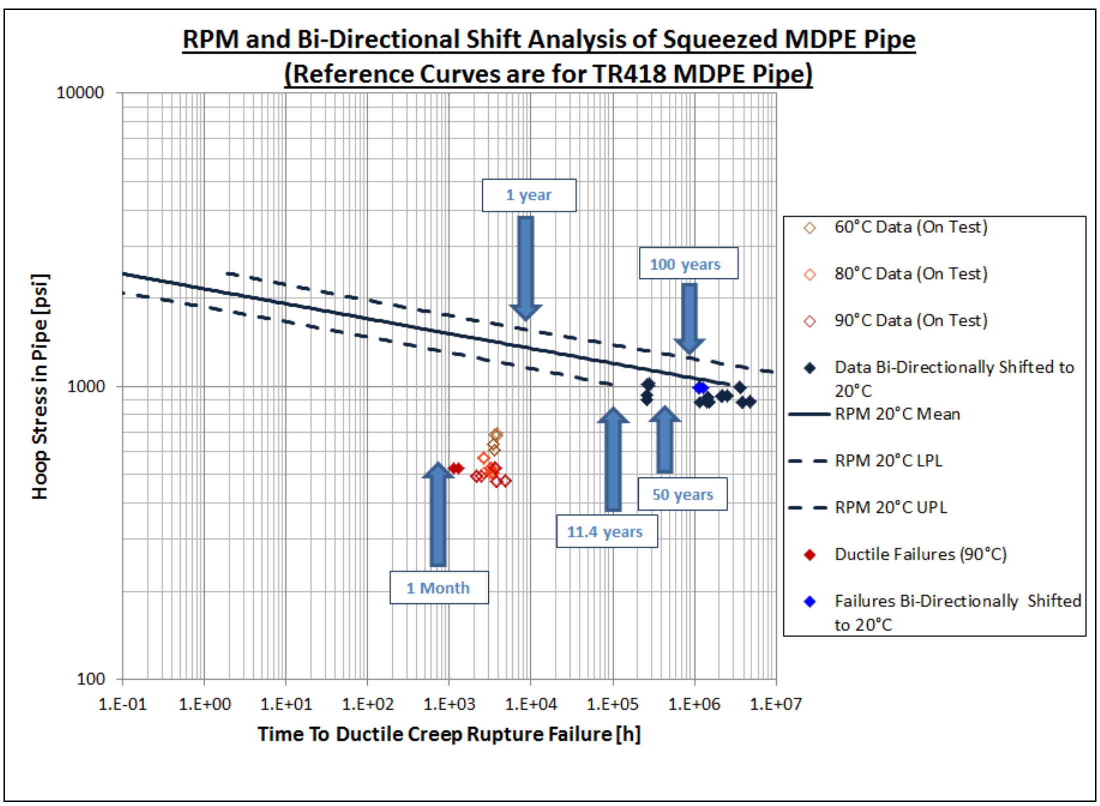

Figure 9. Accelerated hydrostatic test data

7. Conclusions

The simulations results indicated that squeeze-off of small diameter pipe at distances of three (3) pipe diameters from a fused joint are viable and empirical testing is ongoing to verify this indication. COMSOL Multiphysics's user interface and functionalities allowed for a relatively straight forward implementation of a fully parametric model in terms of geometry and boundary conditions. Additionally, the meshing capabilities and ODE functionality of COMSOL enabled the creation of a finite element model that is capable of simulating the large, triaxial deformations encountered in PE pipe squeeze-off.

Future work is planned to further calibrate and verify the PE constitutive model by carefully measuring and datalogging pipe deformation and compression loads during squeeze-offs and installation of pipe reinforcement clamps.

8. References

1. Gas Technology Institute (GTI). http://www.gastechnology.org

2. Operations Technology Development (OTD). http://www.otd-co.org

3. Elabbasi N, Bergstrom J, *Constitutive Modeling of Polyethylene in COMSOL Multiphysics*, COMSOL Conference 2015, Newton MA.

4. *Handbook of PE Pipe*, 2^{nd} Edition, Plastics Pipe Institute. http://plasticpipe.org/publications/pe_handbook.html

5. Image taken from http://www.doitpoms.ac.uk/tlplib/beam_bending/printall.php

9. Acknowledgements

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