New Developments in Strain Hardening Modulus for Polyethylene Pressure Piping Applications

Dr. Bryan E. Hauger
Bryan Hauger Consulting, Inc.

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Overview

- Objectives
- Introduction
  - Strain Hardening Modulus (SHM) and Natural Draw Ratio (NDR)
- Case Studies
  - 2005 – The Origin of ISO 18488
  - 2012 – Statistics of SHM
  - 2015 – Early Log PENT / SHM correlation
  - 2016 – Log PENT / ISO 18488 SHM correlation
- Statistical Analysis
- Current ASTM Work
- Conclusions

Objectives

- Introduce ISO 18488 test method for measurement of strain hardening modulus (SHM)
- Illustrate the promise of SHM to replace the PENT test
- Provide some statistical context to the ISO 18488 test
- Update the status of efforts to introduce an ASTM test method for SHM

Background on SCG

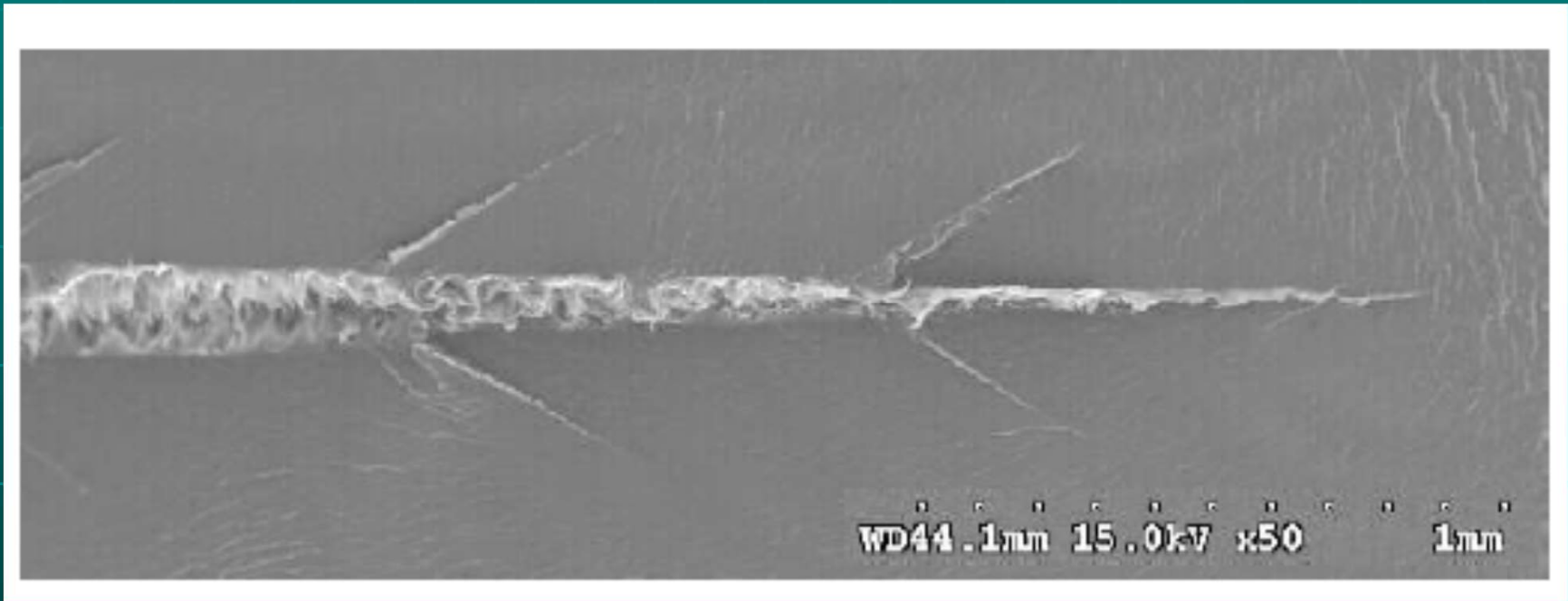
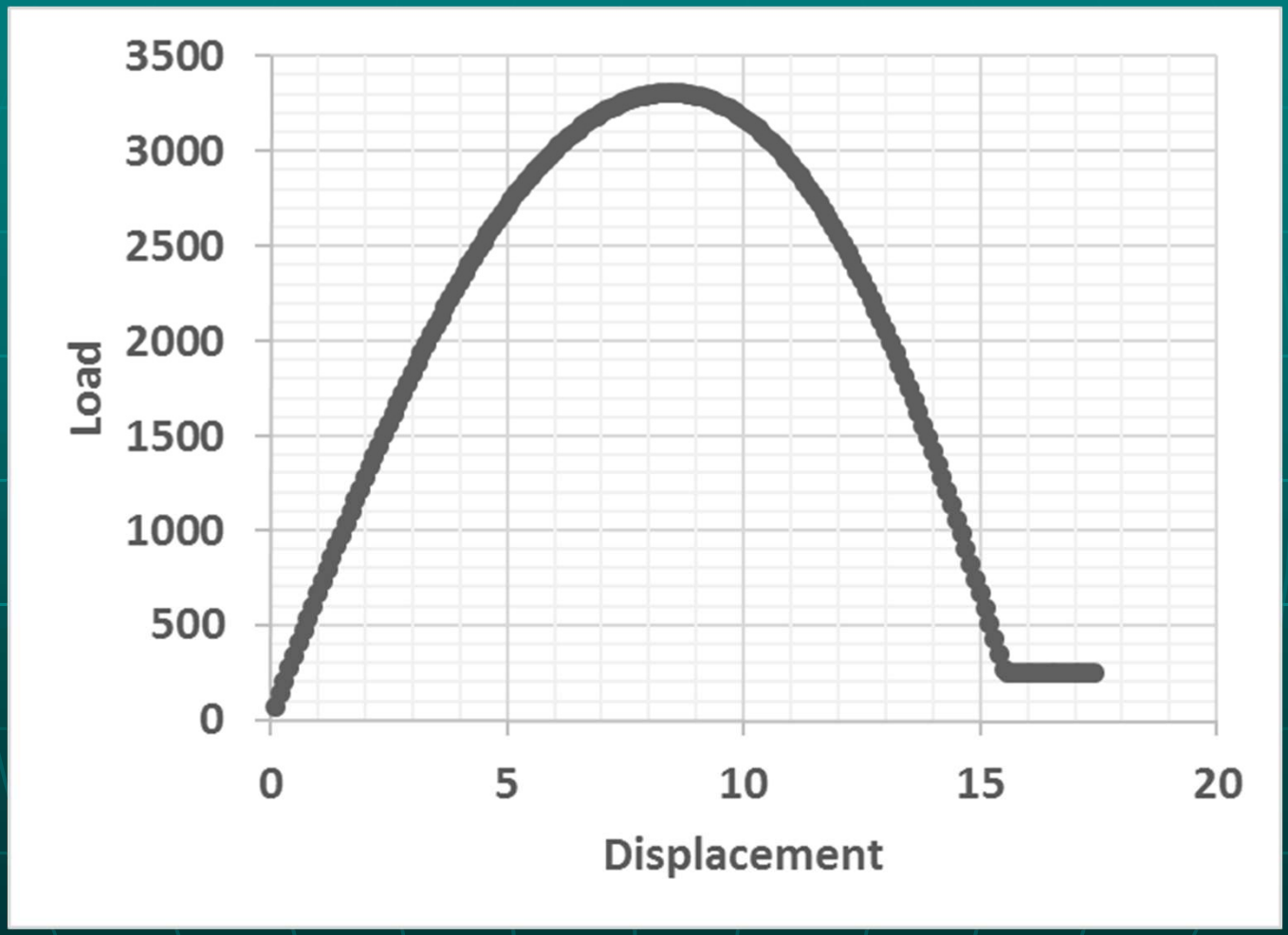
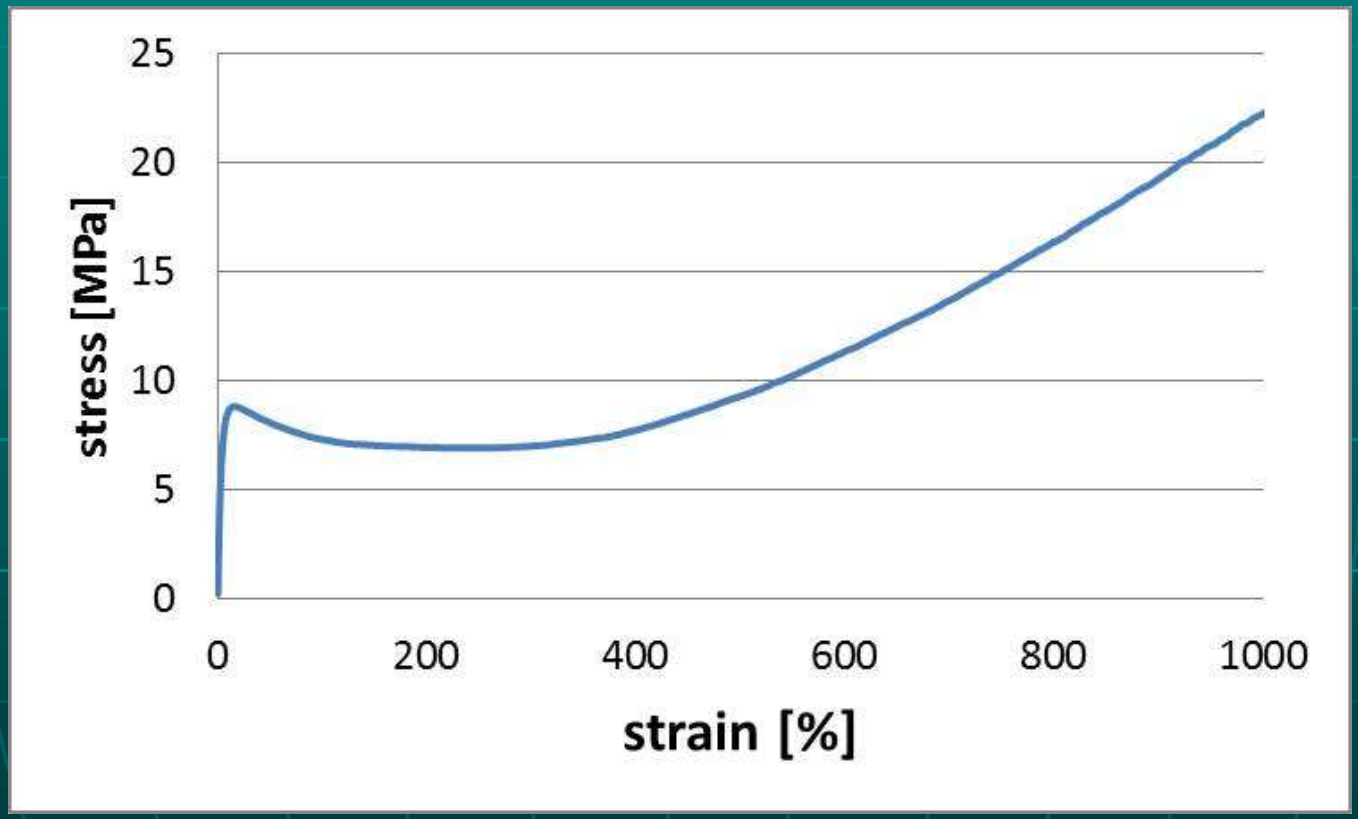


Image from Z. Zhou, et. al "Temperature Effects on Slow Crack Growth in Pipe Grade PE", SPE ANTEC Proceedings, 2010, p. 680.

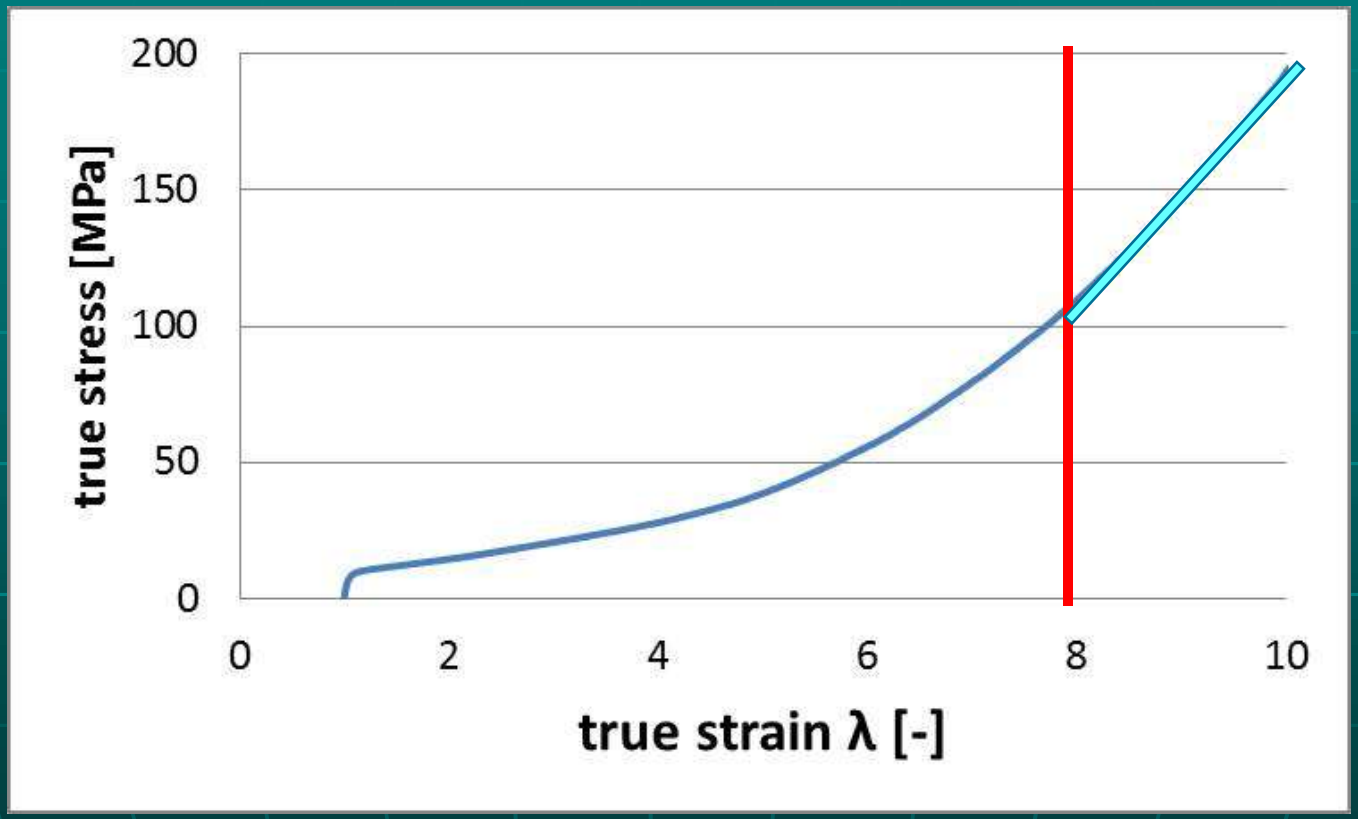
Stress Strain Curve for PE



Stress Strain Curve for PE



True Stress Strain Curve for PE



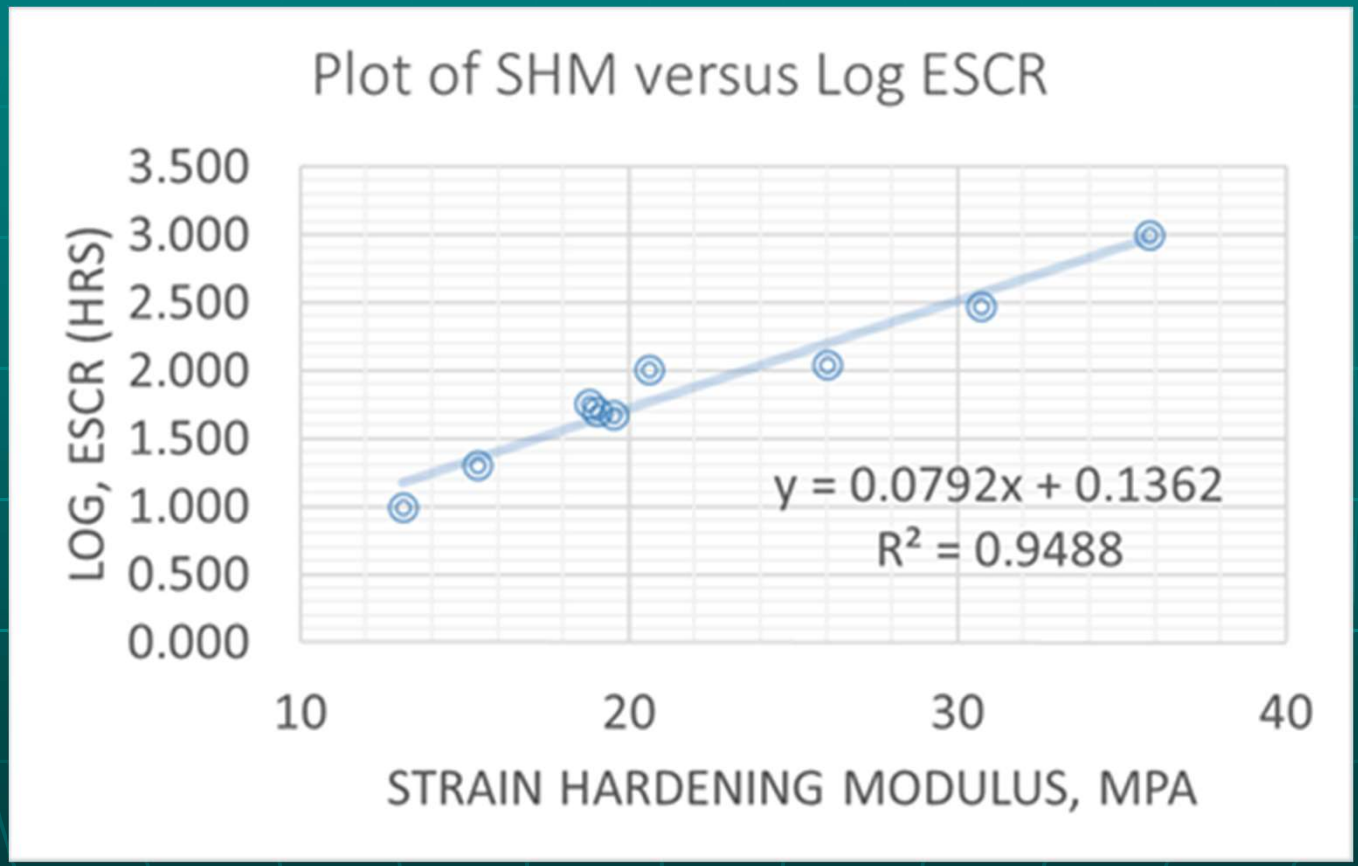
2005 – The Origin of SHM

- "Strain Hardening Modulus As a Measure of Environmental Stress Crack Resistance of High Density Polyethylene" Polymer, 46, (2005), 6369-6379.
- Blow molding and pipe resins were subjected to both "standard tensile ESCR test" at 75C and an ISO37 type 3 tensile bar at 80C and elongation at 10 mm/min using an optical extensometer

2005 – The Origin of SHM

ESCR (hrs)	SHM	Log ESCR
10	13.1	1.000
20	15.4	1.301
47	19.5	1.672
50	19	1.699
58	18.8	1.763
103	20.6	2.013
112	26	2.049
300	30.7	2.477
1000	35.8	3.000
>2000	47.2	NA

2005 Case Study - SHM versus Log ESCR



2005 Case Study – Molding and Testing

- Press into a sheet at 160°C with a thickness of about 0.3 mm by;
  - heating for 5 minutes at 0 kN load then 3 min at 10 kN load followed by 3 min at 50 kN load and finally cooling to RT at a load of 180 kN
- Anneal for 1 h at 120°C and then slow cool to RT by switching off the heat to the chamber.
- Test specimens (ISO37 type 3) are punched from the pressed sheets.
- 80°C tensile testing with a strain rate of 10 mm / minute and measured by optical extensometer

ISO 18488 Molding

- Press into a sheet at 180°C of thickness either 0.30 (+0.03 / -0.05) mm or 1.00 (± 0.1 mm) by;
  - heating for 5 to 15 minutes at 0 kN load then 5 +/- 1 min at 5 Mpa load followed by cooling to RT under load at 15 +/- 2°C
- Anneal for 1 h at 120 +/- 2 °C and then slow cool to < 40°C with an ave. cooling rate < 2 °C / min.
- Test specimens are slightly modified in Geometry from ISO37 type 3 bars
- 80°C tensile testing with a strain rate of 20 mm / minute and measured by optical extensometer

2012 - Statistics of SHM

	Resin A	Resin B	Resin C
G_p in MPa	82.7	46.6	25.1
Standard Deviation	8.0	2.3	1.1
% Standard Deviation	9.7	4.9	4.4

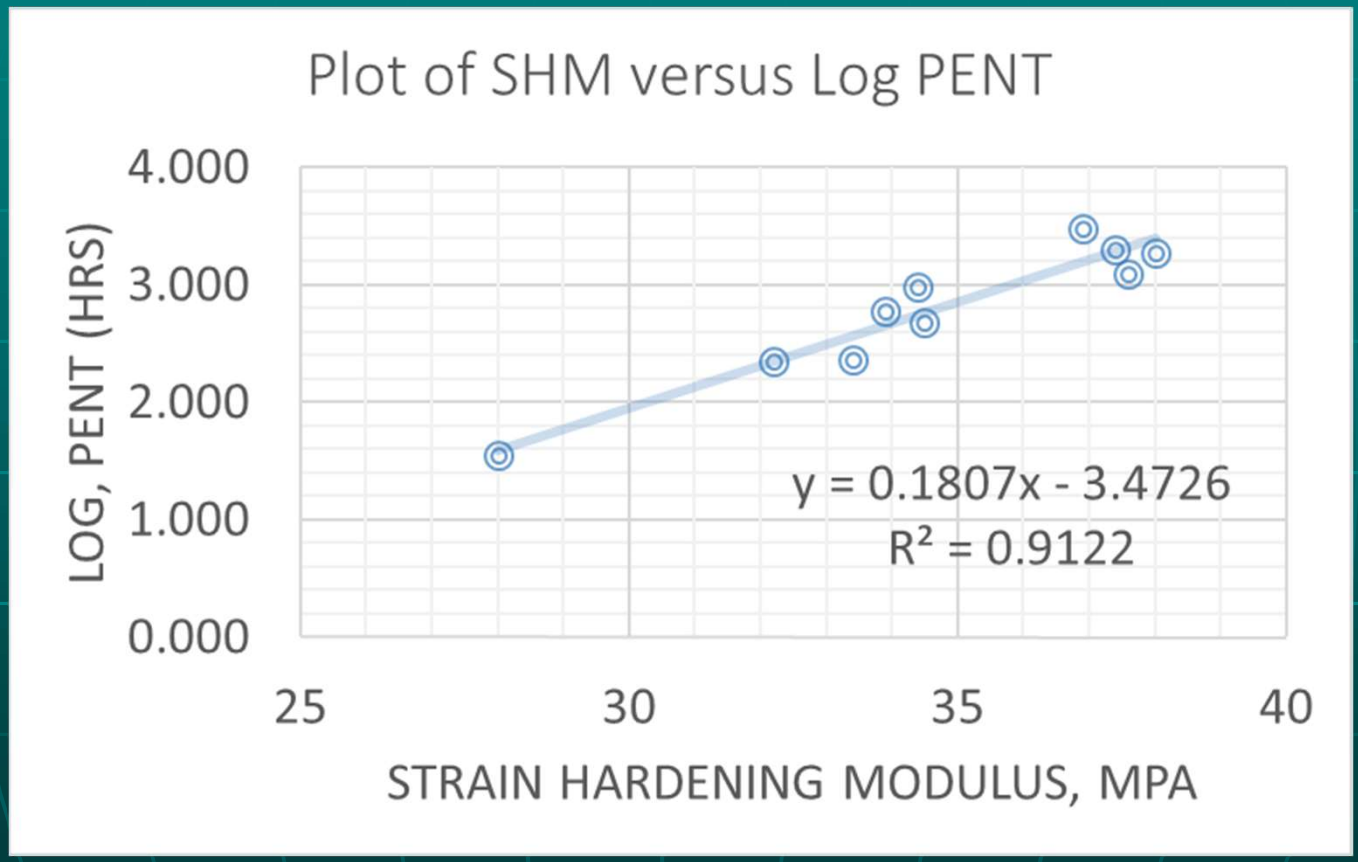
2015 – Log PENT and SHM

- "The Effect of Microstructure on the Slow Crack Growth Resistance in Polyethylene Resins" J. Polym. Eng. Sci., 55, 1018 – 1023 (2015).
- The paper reports work on "polyethylene grades from blow molding up to PE-80, PE-100, and higher resistant to crack grades".

2015 – Correlation of Log PENT with SHM

PENT (est.) (hrs)	Est. G_p MPa	Log PENT
35	28.0	1.544
225	32.2	2.352
230	33.4	2.362
475	34.5	2.677
600	33.9	2.778
950	34.4	2.978
1250	37.6	3.097
1875	38.0	3.273
2000	37.4	3.301
3025	36.9	3.481

2015 Correlation of SHM with Log PENT



Statistical Synthesis on 2015 Data

PENT (est.) (hrs)	Est. G_p MPa	3 X Est. Standard Deviation, Mpa	Log PENT
35	28.0	4.2	1.544
225	32.2	4.8	2.352
230	33.4	5.0	2.362
475	34.5	5.2	2.677
600	33.9	5.1	2.778
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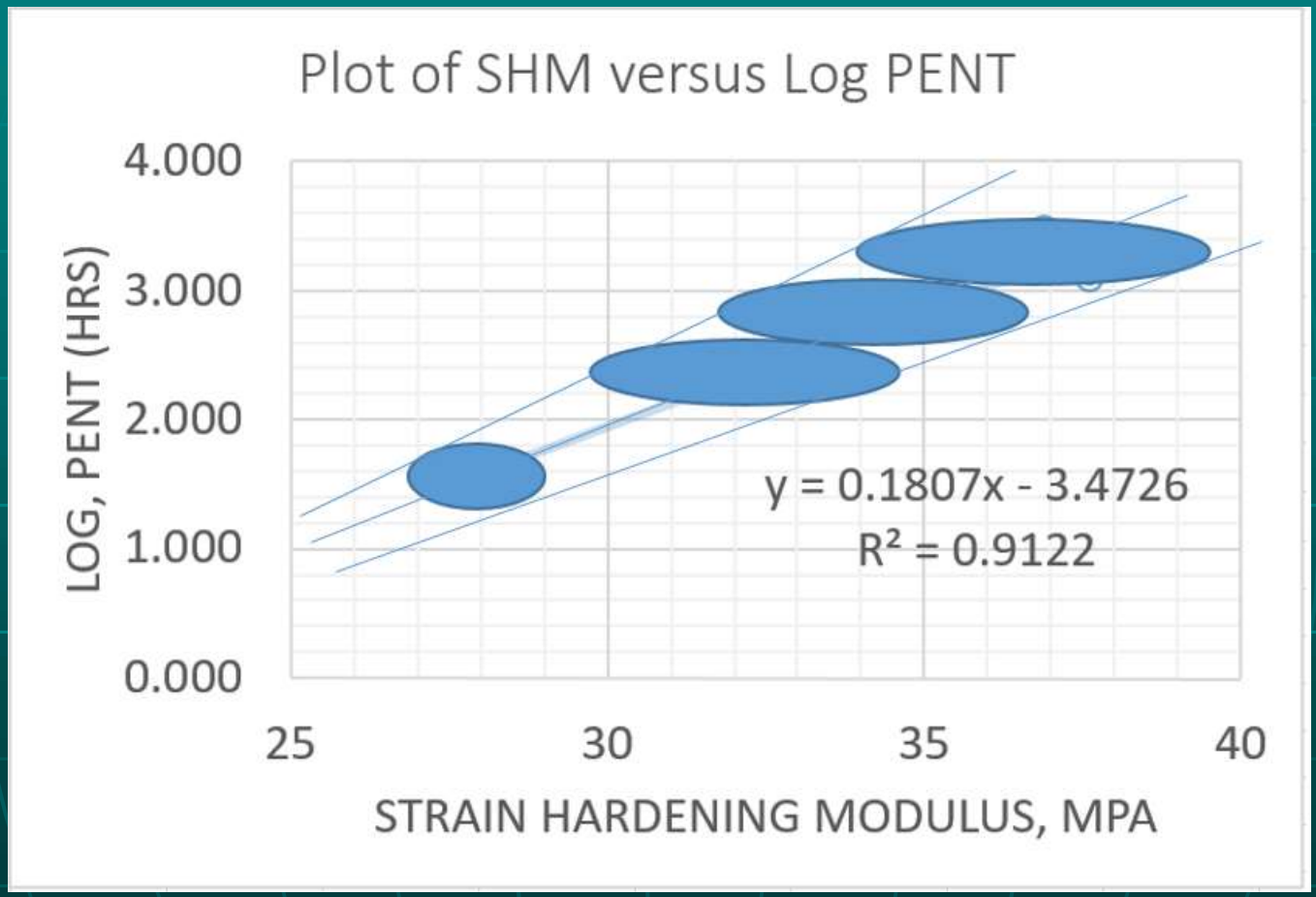

2016 Correlation of SHM with Log PENT

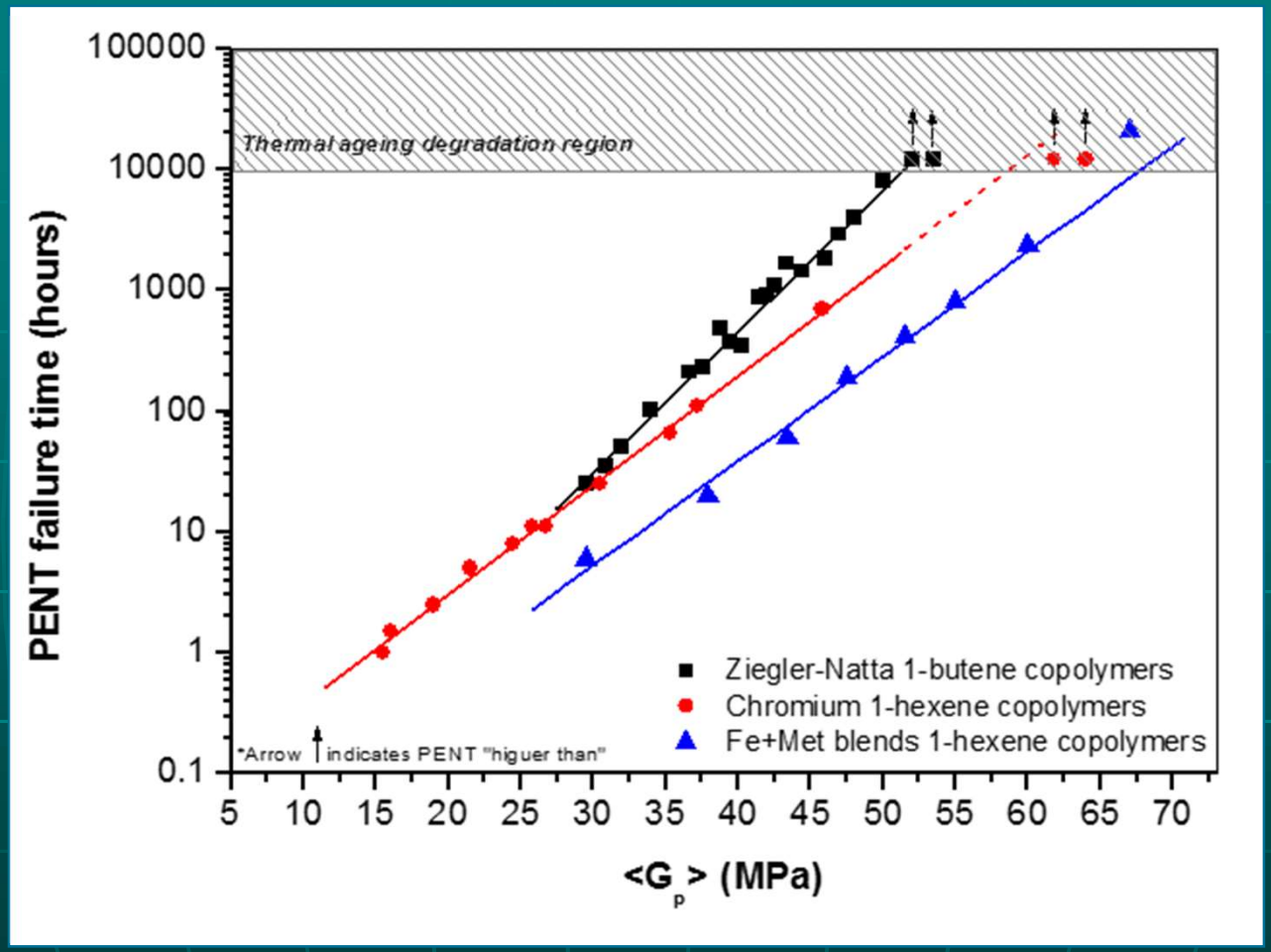

Image from C. Domínguez, et. al ""Limits on the Slow Crack Growth Resistance Evaluation for the PE100 and PE100RC Polyethylene Resins". Plastics Pipes XVIII, Munich, Germany, September 2016.

Current ASTM Work

- ASTM test method titled "Measurement of Strain Hardening Modulus on Polyethylene Materials used in the Manufacture of Stress-Rated Pipe".
- Once that Test Method is agreed upon in the consensus process, then work will start to include precision and bias testing
- Document if pigments including carbon black are tolerated

Conclusions

- ISO 18488 is the basis of current industry efforts to measure SHM.
- The ability to use SHM to obtain a correlation to PENT on PE pressure pipe resins is documented and supported by statistical analysis.
- An ASTM test method is currently under development which should address any remaining barriers to industry adoption.

Questions