POLYOLEFIN PIPES INTERNATIONAL CONFERANCE

Instructions and technical framework for recycling of PE pipes and their reusing in the production process to reduce environmental concerns

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IRANIAN ASSOCIATION OF PE PIPE & FITTING PRODUCERS

Instructions and technical framework for recycling of PE pipes and their reusing in the production process to reduce environmental concerns

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Introduction

- Corrugated HDPE pipe was first manufactured in the early 1970s for agricultural drainage applications.

- In the early 1980s, they were used in highway and railroad applications.

- Today, in the U.S. 1 billion pounds of HDPE go into the ground as pipes annually for agriculture, private and public storm drains and highway/railroad culverts.

● PCR & PIR PE materials in

✓ small diameter pipes in agricultural and land drainages

✗ pipes used for highway applications

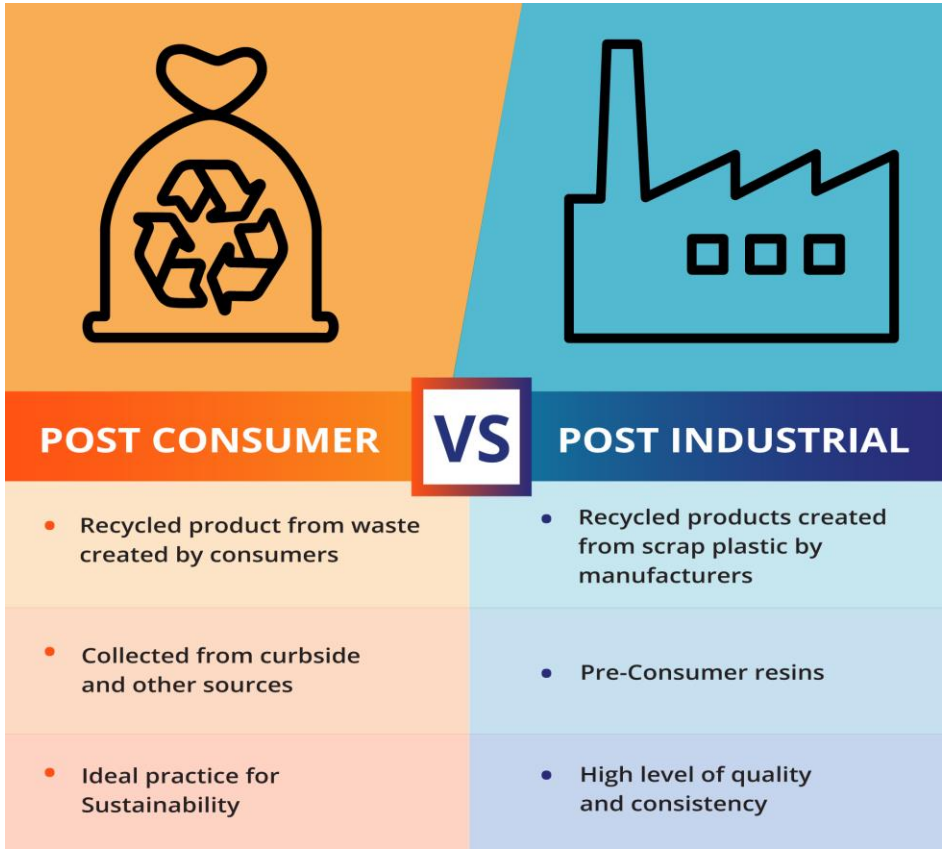
● only PIRs from one's own manufacturing process ("re-work" or "regrind") in

✓ pipes used for highway applications

● Benefits of incorporating recycled materials into corrugated HDPE pipe.

✓ economic: 20% or more savings

✓ environmental standpoint



- Significant public interest and demand in using more sustainable resources in transportation infrastructures.

- Association of Postconsumer Plastic Recyclers (APR) report: in 2013, 28 % and in 2014, 35% of recycled HDPE is used to make pipe in the US.

- **The main challenge:**
  PCRs may contain impurities and their long-term behavior is still not fully understood.

- However, the failure phenomenon of *gravity corrugated sewer pipes* is fundamentally different from that affecting pressure pipes.

- Therefore, if the use of PCRs seems inappropriate for the long-term performance expected of pressure pipes, they probably can instead be used in the production of *gravity corrugated pipes.*

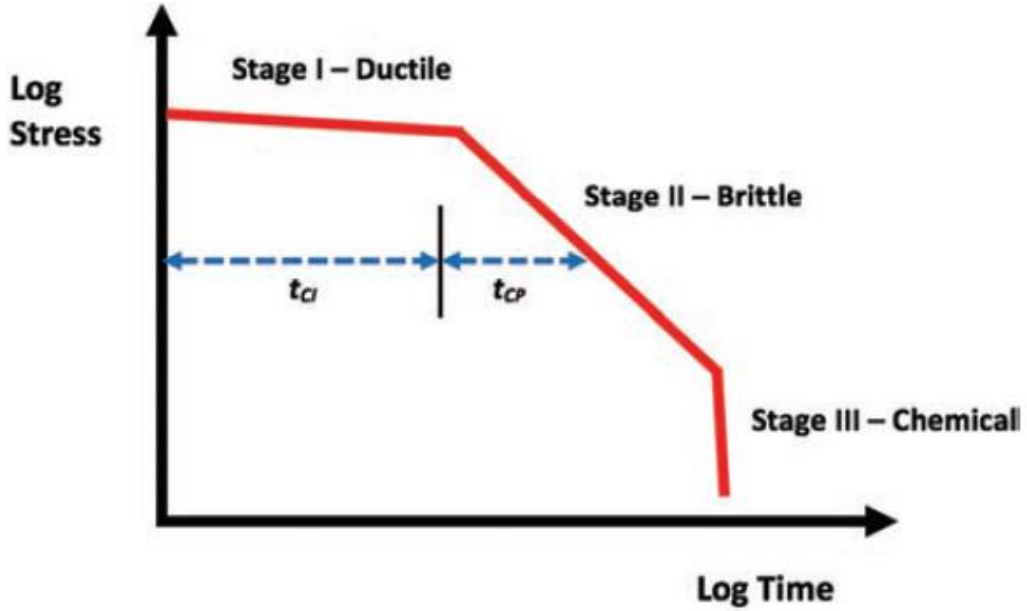
Failure mechanism of HDPE gravity corrugated pipes

- Due to low internal or external pressures, Stage I failures are not typical in these pipes

- Stage II failures by slow crack growth (SCG) are primary service-limiting failure mode of concern for these pipes

- Contaminants are very important since they may serve as stress risers to initiate cracking

- Testing notched virgin HDPE/PCR samples are insufficient because effect of contaminants is ignored



$$t_{SCG} = t_{CI} + t_{CP}$$

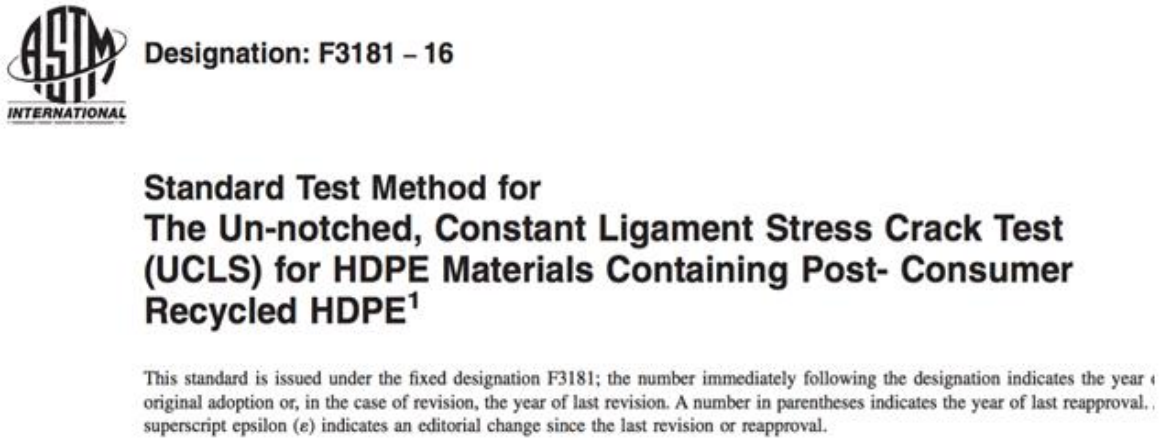
t_{SCG} = Total time to failure
t_{CI} = crack initiation time
t_{CP} = crack propagation time

Implemented tests to predict long-term behavior of HDPE drainage pipes

The Unnotched Constant Ligament Stress (UCLS) Test

- A standard test method to determine the stress crack resistance of corrugated HDPE pipes containing PCRs.

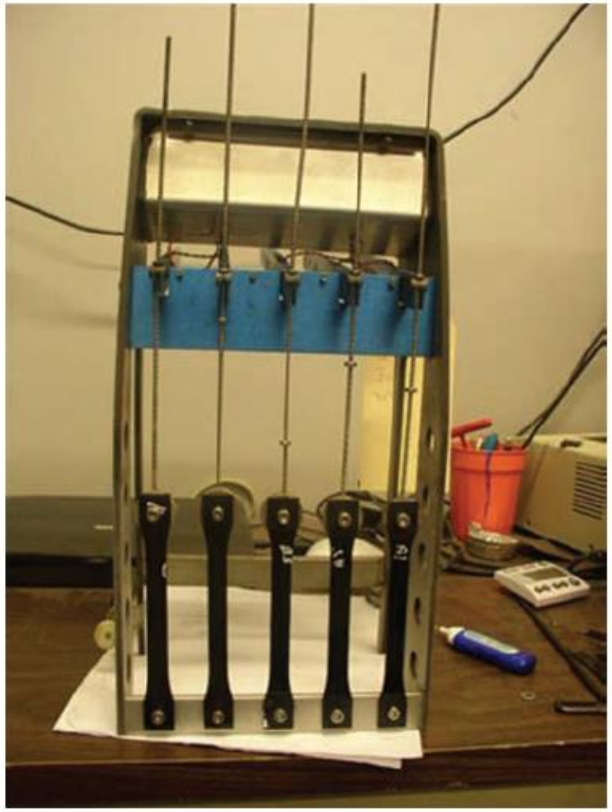
- Unlike NCLS method (ASTM F2136), UCLS test uses un-notched specimens and relies on the role of contaminants as stress risers for originating the crack.



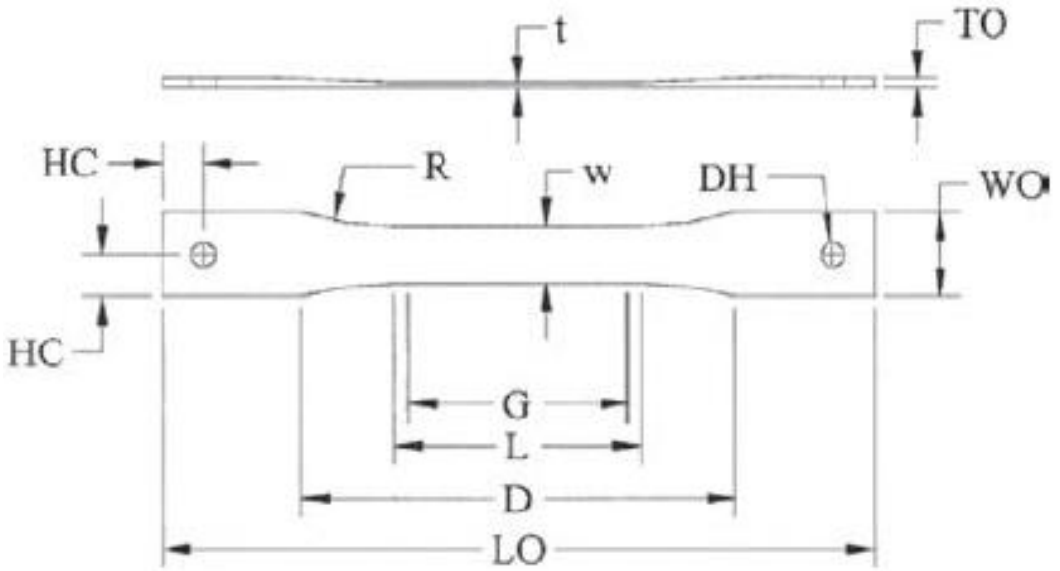
Designation: F3181 – 16

Standard Test Method for
The Un-notched, Constant Ligament Stress Crack Test (UCLS) for HDPE Materials Containing Post- Consumer Recycled HDPE[1]

This standard is issued under the fixed designation F3181; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.



UCLS test apparatus.



UCLS test specimen

- UCLS test is conducted in deionized water at multiple temperatures and stresses which can be bi-directionally shifted to predict the service life at various stresses and temperatures.

Property	Test Method	M 294 Req't.	Pipe 1	Pipe 2	Pipe 3	Pipe 4	Pipe 5	Pipe 6	Pipe 7	Pipe 8	Pipe 9
PCR Content (%)	Per Mfcr.	0	0	49[1]	98[1]	49[1]	0	98[1]	98[1]	54[1]	59[1]
Density[2] (g/cc)	ASTM D1505	0.948–0.955	0.963[1]	0.966[1]	0.940[1]	0.971[1]	0.949	0.958[1]	0.944[1]	0.951	0.948
Melt Index (g/10 min)	ASTM D1238	< 0.40	0.12	0.30	0.52[1]	0.20	0.19	0.63[1]	0.48[1]	0.07	0.016
UCLS[5] (h)	ASTM F3181	N/A	1271	99.2	15.7	97.5	1432	19.4	19.3	141.0	70.2

M Pluimer, et al., National Cooperative Highway Research Projct (NCHRP) 870 Report, Transportation Research Board, Washington, DC, 2018.

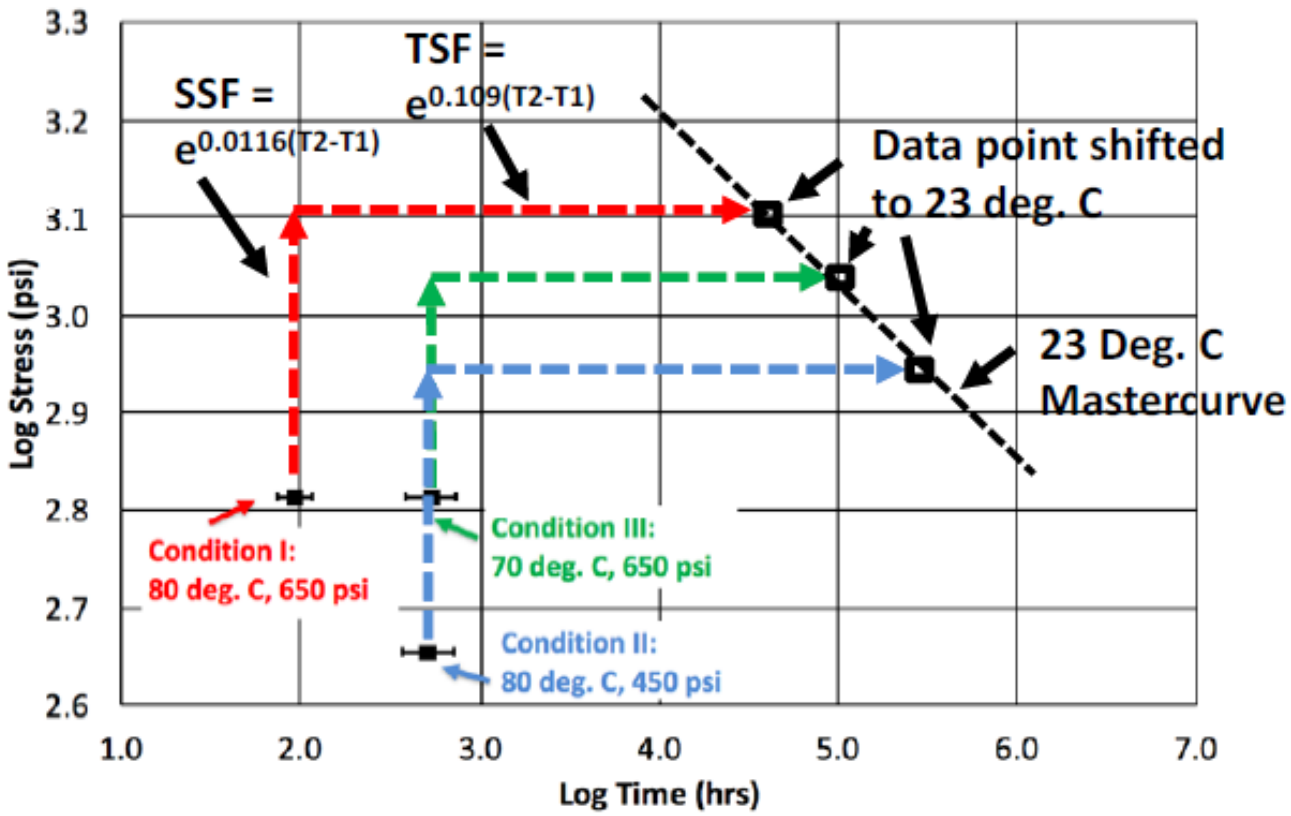
Predicting Service Life with the UCLS Test

Test five specimens at these conditions:

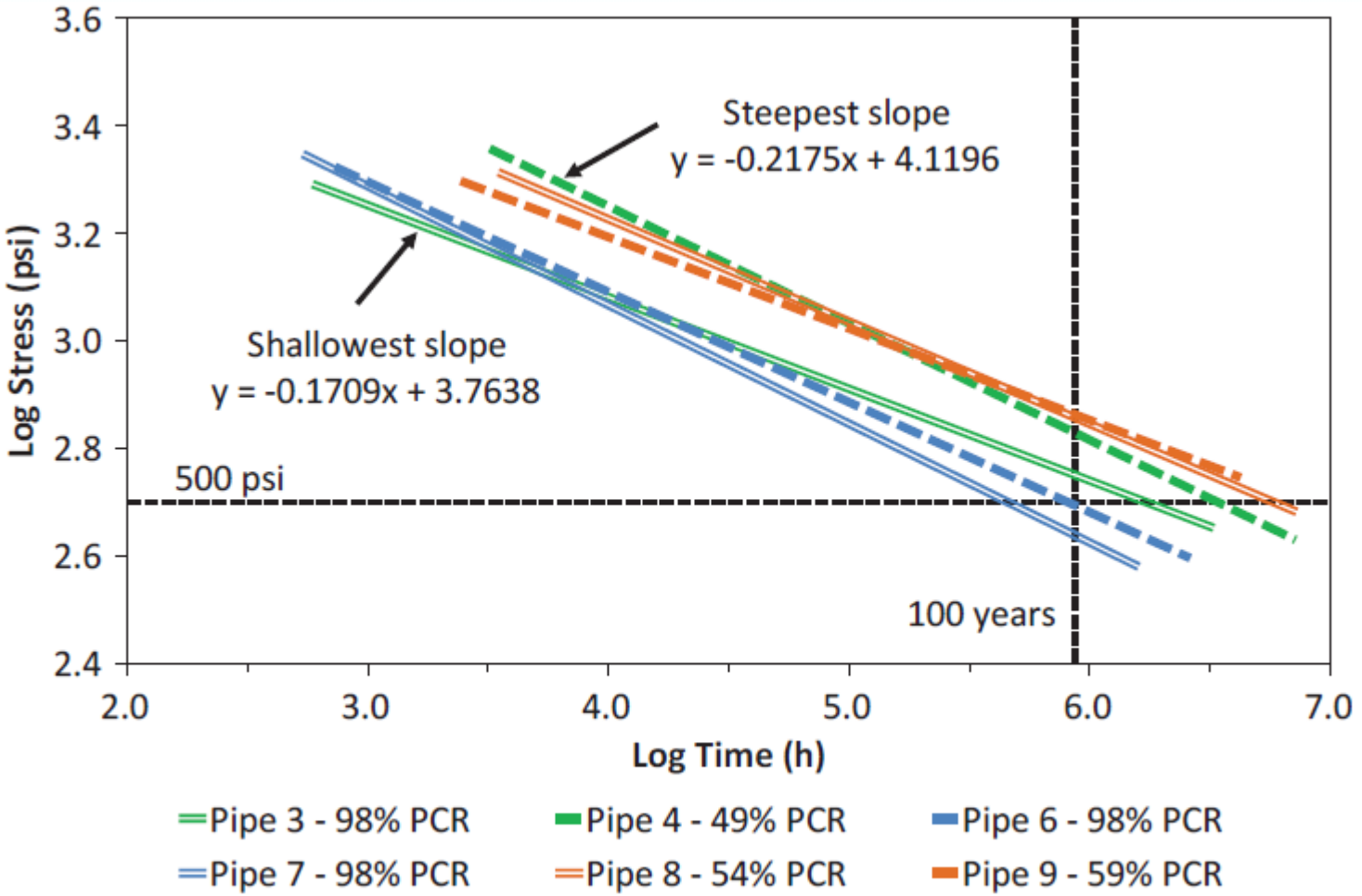
I) 80°C and 650 psi of stress
II) 80°C and 450 psi of stress
III) 70°C and 650 psi of stress

$$\text{Stress Shift Factor} = e^{0.0116(T2-T1)}$$

$$\text{Time Shift Factor} = e^{0.109(T2-T1)}$$



M Pluimer, et al., National Cooperative Highway Research Project (NCHRP) 870 Report, Transportation Research Board, Washington, DC, 2018.



UCLS failure data for all pipes shifted to 23°C

Validation of Service Life Prediction Model

Pipes in constant deflection test frames

assembled load chambers

ET Shaheen, PhD thesis, Ohio University, 2018.

- According to the constant deflection test, corrugated HDPE pipes can be successfully manufactured with PCR content of 0% to 49% to meet AASHTO requirements.

- Importance of uniform distribution of PCRs throughout the pipe.

Pipe	Description	PCR	Predicted Time to Cracking	Actual Time to First Cracking
Pipe 1	30 in. M294 pipe	0%	> 2 yrs.	> 1 yr. - No cracks
Pipe 2	30 in. F2648 pipe	49%	> 2 yrs.	> 1 yr. - No cracks
Pipe 3	30 in. Custom pipe	98%	58 – 148 days	101 days
Pipe 4	30 in. F2648 pipe	49%	1.4 – 3.1 yrs.	> 1 yr. - No cracks
Pipe 5	30 in. M294 pipe	0%	> 2 yrs.	> 1 yr. - No cracks
Pipe 6	30 in. Custom pipe	98%	71 – 220 days	185 days
Pipe 7	30 in. Custom pipe	98%	73 – 172 days	185 days
Pipe 8	30 in. F2648 pipe	54%	203 - 578 days	> 306 d - No cracks
Pipe 9	30 in. F2648 pipe	59%	139 – 357 days	300 days

- According to these test results, the UCLS test service life prediction model is validated

Creep master curves by Stepped Isostress Method (SSM)

- Accelerated tests are used to characterize behaviors such as creep response and creep rupture behavior:

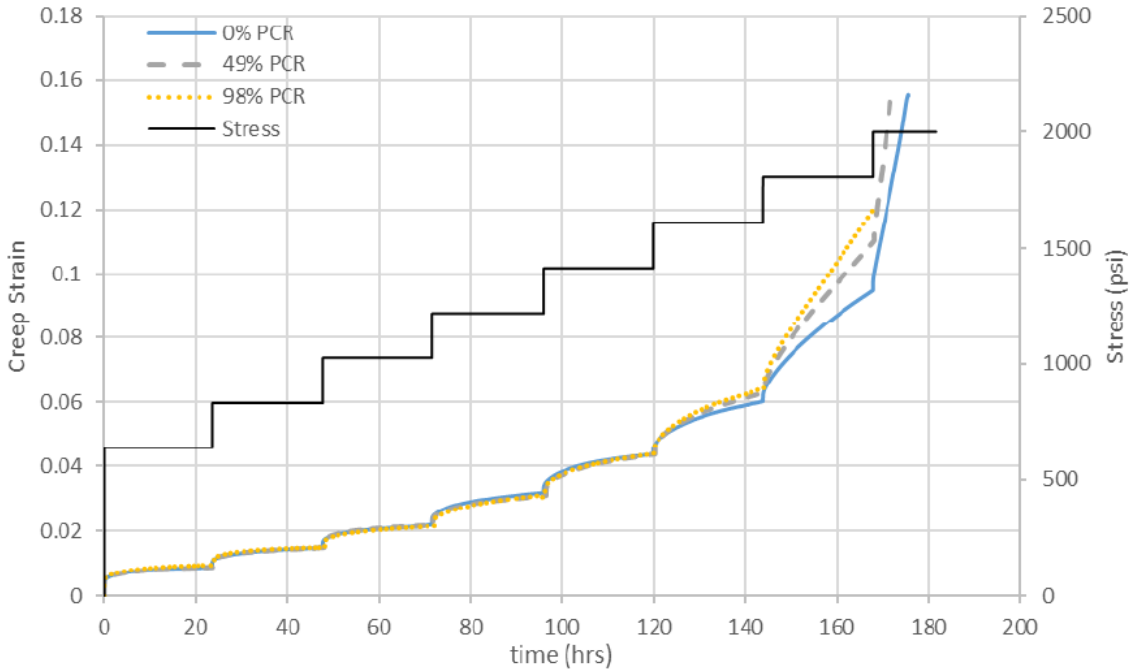
  - Time Temperature Superposition Principle (TTSP)
  - Stepped Isothermal Method (SIM)
  - Time stress superposition principle (TSSP)
  - Stepped Isostress Method (SSM)

- SSM may be promising since it uses stress as an activation energy instead of heat; no oven is required.

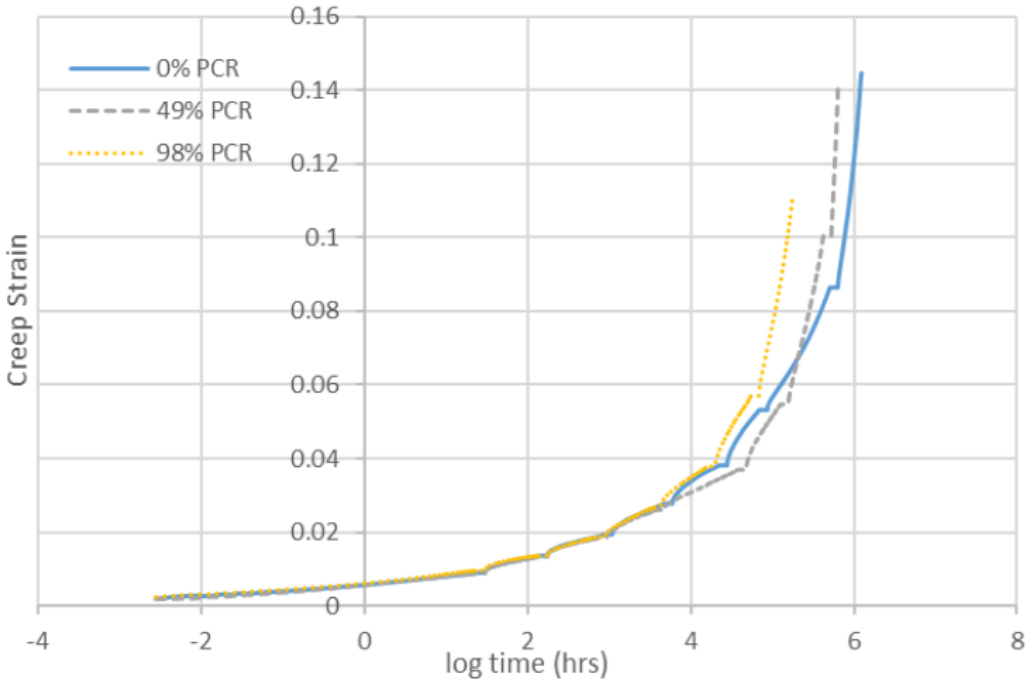
ET Shaheen, PhD thesis, Ohio University, 2018.

Loading the HDPE Pipe Specimens Using SSM Load Frame

Subjecting a single sample to a number of tensile load steps.

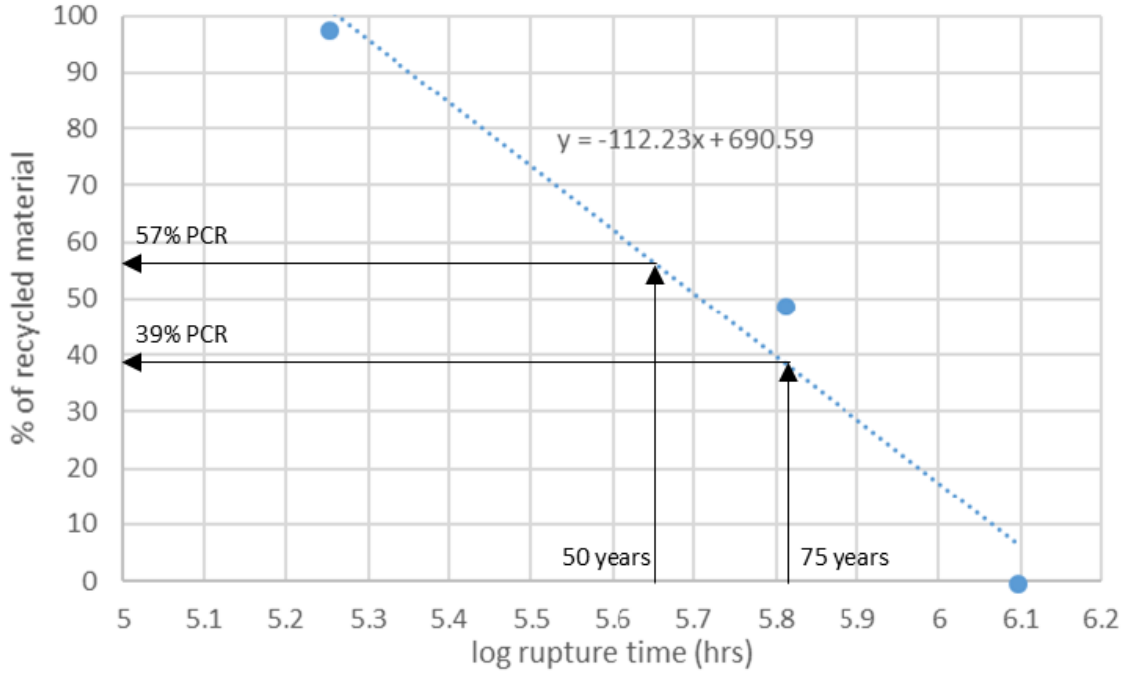


SSM Creep Strain Test Results



Creep Master Curve of 0%, 49%, and 98% PCR Specimens

ET Shaheen, PhD thesis, Ohio University, 2018.



Rupture Times of SSM for HDPE Specimens

Maximum percentage of PCR allowed in HDPE is interpolated to be 57% and 39% for 50-year and 75-year service life spans.

ET Shaheen, PhD thesis, Ohio University, 2018.

Other Requirements for Pipes Manufactured with PCRs

- *NCLS Requirement*

  The pipes should have an NCLS value of 24 h,
  with no specimen having less than 17 h (ASTM F2136)

- *Oxidation Induction Time Requirement*

  An OIT of 20 min. (ASTM D38950 is suggested

- *Tests for Contaminants*

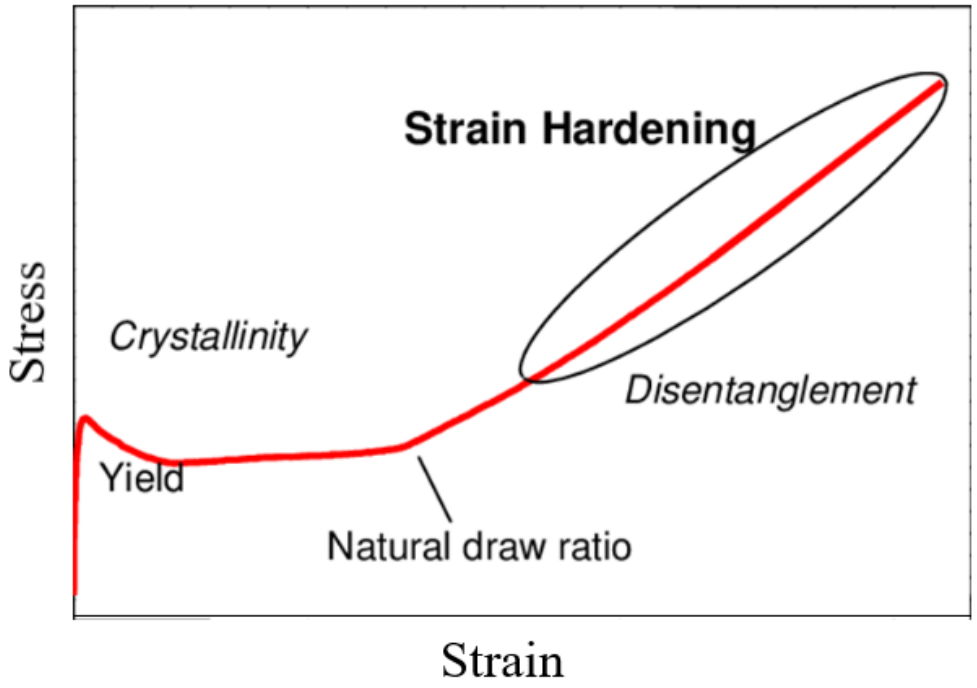
  Break strain of 150% is suggested since Break strain a relatively quick check for contaminants

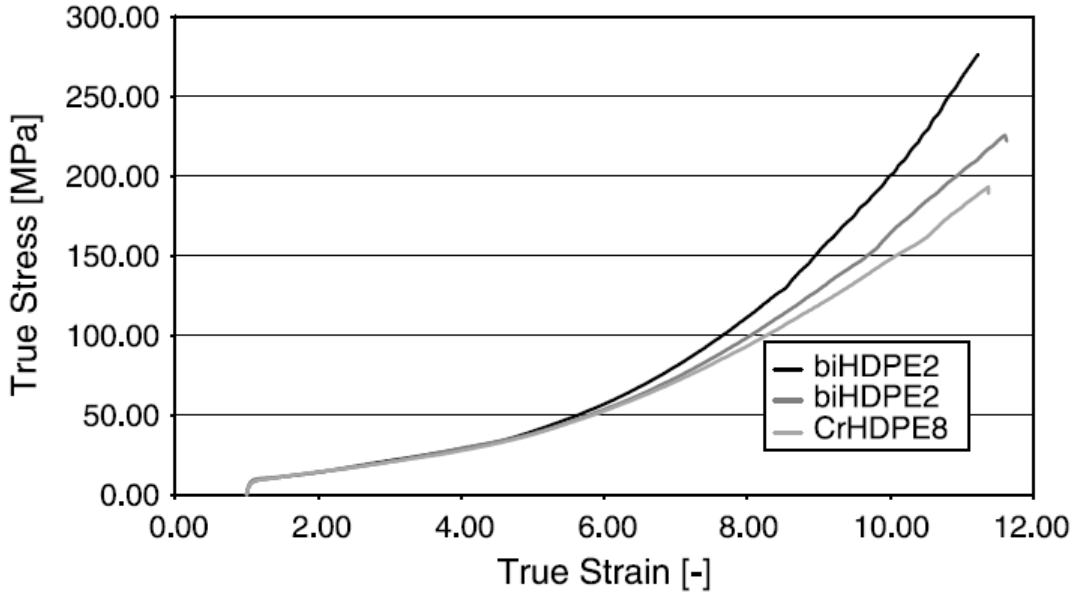
- *Pipe stiffness, flattening performance, impact resistance*

  According to AASHTO M 294

Potential tests to predict SCG resistance

Strain hardening modulus

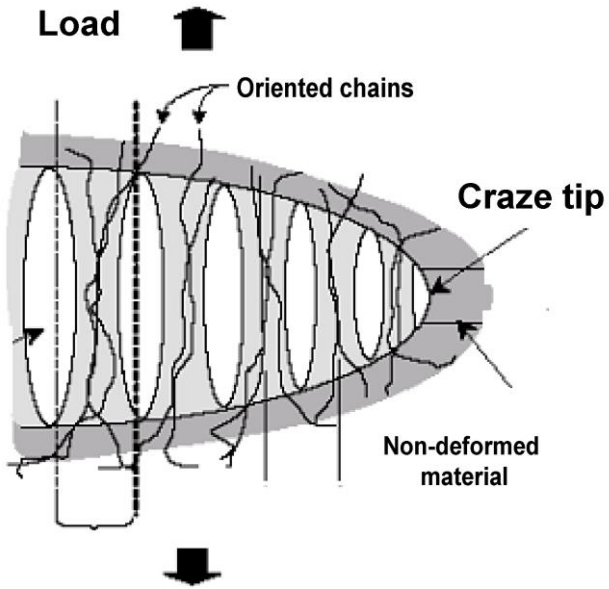




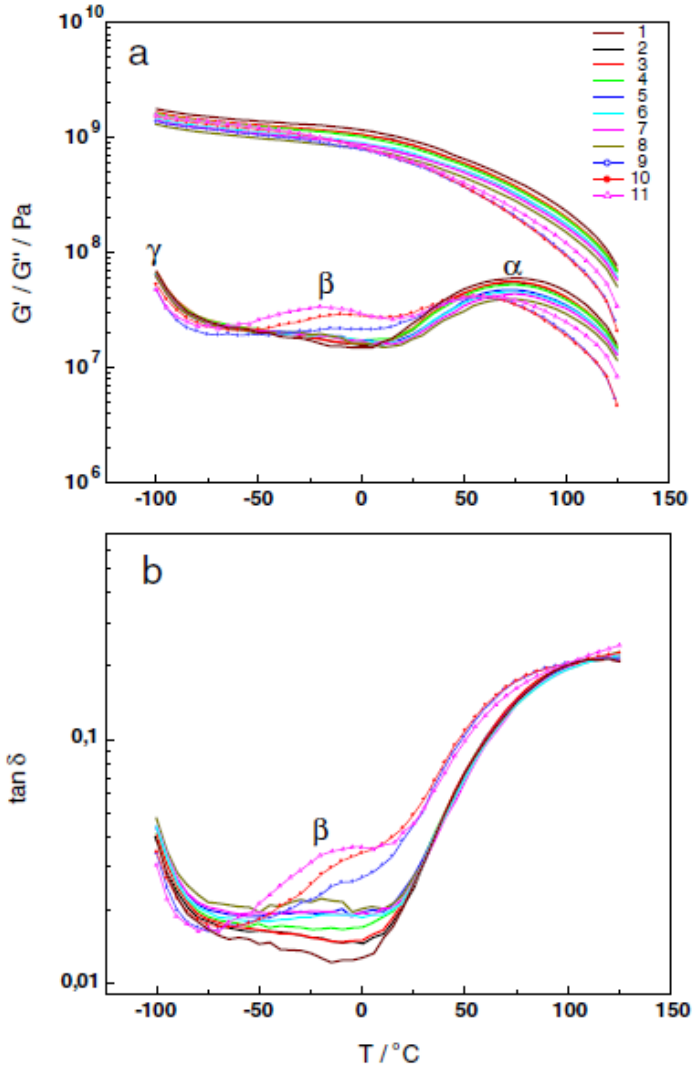
Pipe grade HDPEs (80 °C, 10 mm/min)

L. Kurelec et al., Polymer (2005)

Quantifying mobility of amorphous phase



Men et al., Eur. Phys. J. E (2004)



Sample	M_w 10^5	M_w/M_n	Type
1	1.2	7.7	H
2	2.1	8.9	H
3	2.6	10.9	H
4	3.2	11.5	H
5	4.1	8.3	H
6	6.8	8.2	H
7	6.2	7.2	H
8	8.1	8.5	H
9	3.9	22	UMB
10	3.3	38	BM1
11	4.4	44	BM2

Economic/Environmental Implications of PCR and nanoclay in drainage pipes

$$\text{Changes in Mass } (\%) = \left[\frac{\frac{\text{Elastic Modulus}}{\text{Crystallinity}}[\text{Conventional}]}{\frac{\text{Elastic Modulus}}{\text{Crystallinity}}[\text{Alternative}]} - 1\right] \times 100$$

Estimated mass reduction based on material index

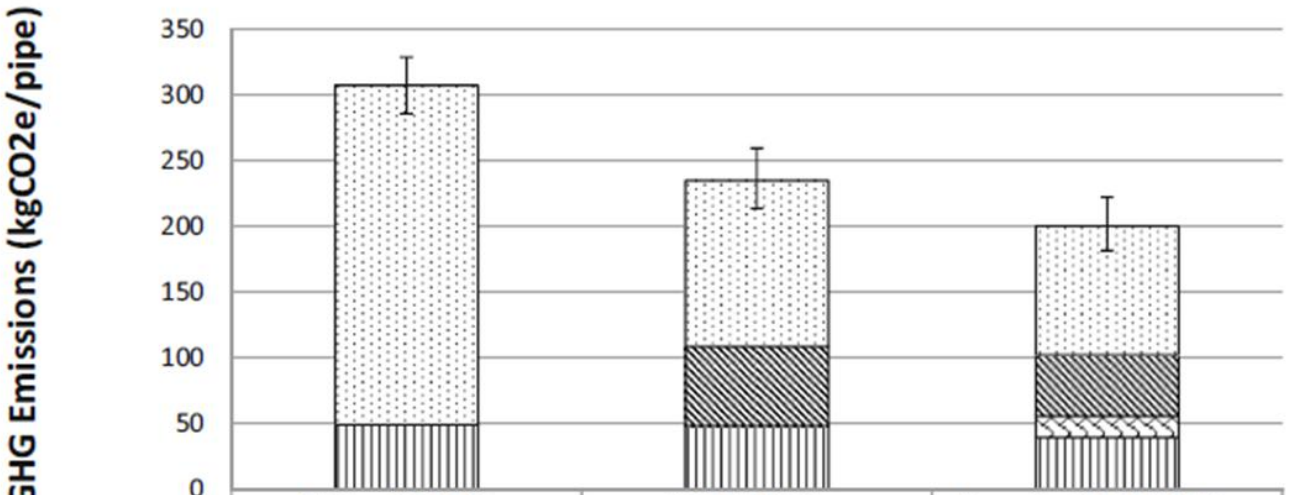
Material	Crystallinity (%)	Elastic modulus (MPa)	Material index (M)	Primary mass reduction (%)	Mass of 20-ft pipe (kg)
Pristine HDPE	67.2	869	12.9		103
HDPE/PCR	68.8	909	13.2	−2.1	101
Nanoclay HDPE/PCR	67.9	1091	16.1	−19.5	82

Nguyen et al., J Polym Environ (2017)

	Pristine HDPE Pipe	HDPE/PCR Pipe	Nanoclay HDPE/PCR Pipe
Pristine HDPE	6554	3208	2480
PCR-HDPE	0	386	298
6% nanoclay	0	0	233
Pipe Formation	330	323	265

Life cycle energy for the production of 20-foot pristine HDPE, HDPE/PCR and nanoclay HDPE/PCR pipes

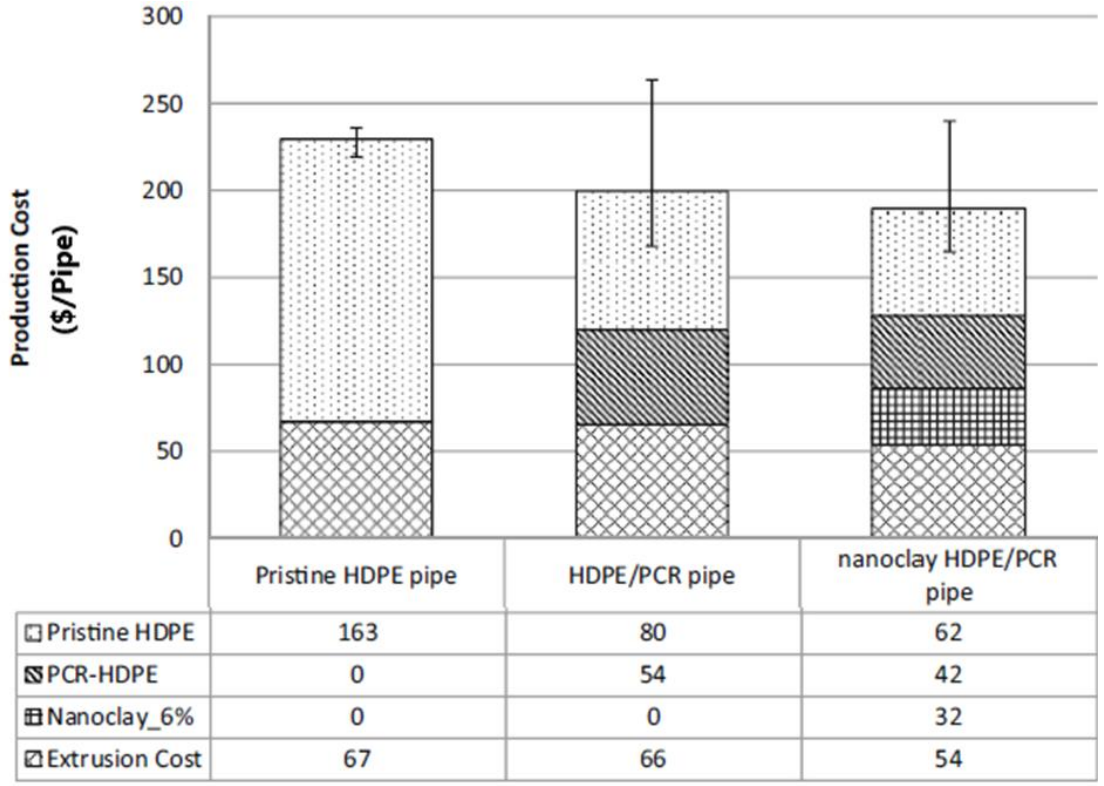
Nguyen et al., J Polym Environ (2017)



	Pristine HDPE Pipe	HDPE/PCR Pipe	Nanoclay HDPE/PCR Pipe
Pristine HDPE	258	126	98
PCR-HDPE	0	61	47
6% nanoclay	0	0	16
Pipe Formation	49	48	39

Life cycle GHG emission for the production of 20-foot HDPE, HDPE/PCR and nanoclay HDPE/PCR pipes

Nguyen et al., J Polym Environ (2017)



	Pristine HDPE pipe	HDPE/PCR pipe	nanoclay HDPE/PCR pipe
Pristine HDPE	163	80	62
PCR-HDPE	0	54	42
Nanoclay_6%	0	0	32
Extrusion Cost	67	66	54

Production cost of 20-foot pristine HDPE, HDPE/PCR and nanoclay HDPE/PCR pipes.

Nguyen et al., J Polym Environ (2017)

Conclusion

- Introducing PCRs into corrugated pipes is a win-win for everybody: taxpayers, state departments of transportation, manufacturers, consumers and our environment

- Main challenge are the presence of impurities in PCRs and full understanding long-term behavior of pipes containing PCRs

- There are implemented tests to assess the long term behaviors of PCR containing pipes, UCLS, SSM,…

- According to the designed test methods, incorporating 40-60% of PCRs to corrugated pipes is allowed

- Nanotechnology may pave the way further to achieving economically/environmentally favorable and durable corrugated pipes containing PCRs


Thank you for your attention