ELECTRIC POWER RESEARCH INSTITUTE

Upcoming EPRI R&D Activities Related to Material Properties of HDPE Pipe

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Recent & Pending EPRI Reports

- 1022565, “Slow Crack Growth Testing of High Density Polyethylene Pipe – 2011 Update”
  - Available ~ 1 week from distribution center (chandy@epri.com)
- 1023004, “Fire Testing of High Density Polyethylene Pipe”
  - Available now from EPRI web
- 1021095, "Seismic Properties of High Density Polyethylene Pipe for Use in Above Ground Applications“
  - Material damping
  - Tensile modulus @ seismic strain rates
  - Shake table testing of vent & drain valve configurations
  - Available end Sept from Distribution Center (chandy@epri.com)

2011-2012 Upcoming Tests

- Upcoming tests
  - Tensile
  - Fatigue
  - Creep & elastic modulus
  - SCG type tests
- All tests will use bimodal resins compliant with the requirements of CC N-755, rev 1
  - 3 resin supplier/pipe manufacturers are intending to supply materials (min PENTs = 2000 hr, 5000 hr, 10,000 hr)
- Tests have not yet been started. Work to date has been on refining plans, procurement, and commercial grade dedication

Prior Tensile Tests

- Prior test (report 1018351) used a unimodal 4710 resin. Objectives:
  - Temperature dependence of below ground compressive stress allowable
  - Data to support above ground tensile allowables
  - End point for creep data
  - End point for modulus as f (strain rate)
- Prior tests found little difference between new and aged materials and axial and hoop directions

Temp (F)	# Specimens	Orientation	Material
50, 70, 140, 160, 180	25	Axial	New
50, 70, 140, 160	20	Axial	Aged
50, 70, 140, 160, 180	25	Hoop	New
50, 70, 140, 160	20	Hoop	Aged
Totals	90		

Upcoming Tensile Tests

- Sufficient number of tests to demonstrate Code compliant resins have tensile properties greater than prior resin tested
  - Follow ASTM D-638-03
  - Tests at 40ºF, 73ºF, 140ºF, 160ºF, and 176 F
  - New materials only
  - Axial or hoop direction only
  - 5 or 6 replicas per test
  - 25 or 30 tests

Prior Fatigue Tests

- Prior fatigue tests used a unimodal 4710 resin. Results in reports 1015062 and 1020439.
- Used a 4' diameter SDR 11 pipe following the procedure of Markl & ASME Section III
  - Included a butt fusion joint, allows a B-F joint to be used anywhere without need for a special SIF
- Test matrix

Temperature (F)	# Specimens	Approx. # Cycles	Frequency (Hz)
50, 70, 140, 160	16	50	1
50, 70, 140, 160	16	1000	1
50, 70, 140, 160	16	10,000	1
50, 70, 140, 160	16	20,000	1
50, 70, 140, 160	16	100,000	1
Totals	80		

Upcoming Fatigue Tests

- Sufficient number of tests to demonstrate Code compliant resins have fatigue properties greater than prior resin tested
  - Tests at 73ºF and 176 F
  - 5000, 10,000, 20,000, 100,000 cycles
  - 4” diameter SDR 11 pipe following the procedure of Markl & ASME Section III
  - Multiple PENT resins
  - 5 replicas/test

Upcoming Creep & Modulus Tests

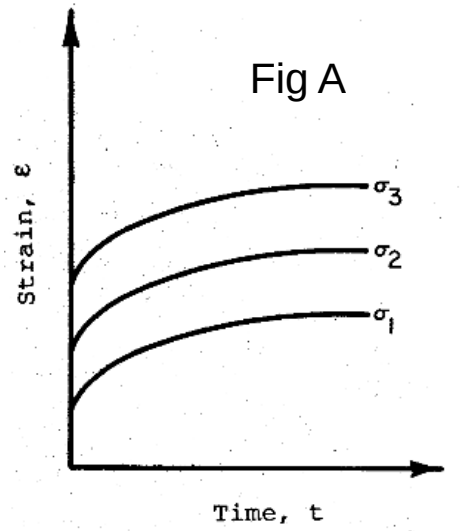
- Objectives
  - Develop creep & modulus data for code compliant resins
  - Answer question as to whether modulus is a function of stress, time, and temperature, or independent of stress
  - Provide Modulus vs Temperature curves
- Planned tests (tentative)

Test Set	Temp	30% Sy	40% Sy	50% Sy
1	1	6	6	6
2	2	6	6	6
3	3	6	6	6

Upcoming Creep & Modulus Tests (continued)

- Process
  - Convert displacement vs time data to strain vs time
  - Form “best-fit” strain vs time curves for each temperature (see Fig A)
  - For each temperature, form new curves of ε/σ vs time
  - At each temperature, if the curves collapse, then material is linear and modulus is independent of stress (see Fig B)
  - If not, the material is nonlinear and modulus as a function of stress and temperature (Fig C)

Fig A



Typical uniaxial creep curves for ductile polymers.

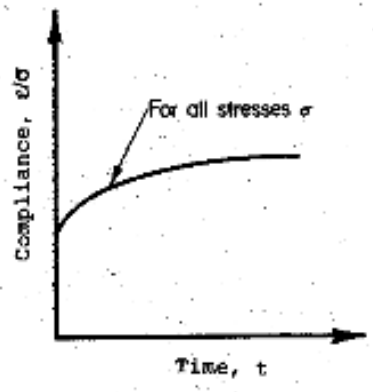


Fig B

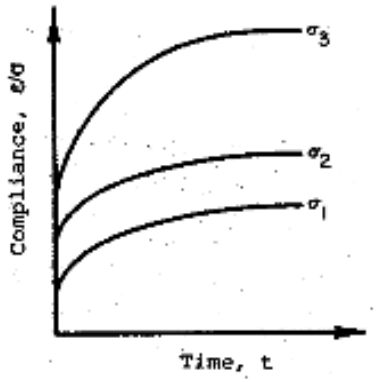
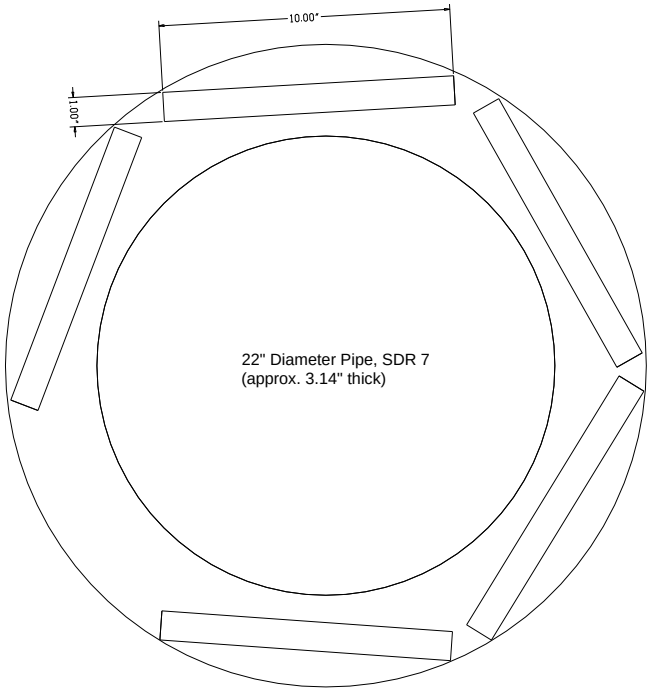


Fig C

Upcoming Creep & Modulus Tests (continued)

- 1” x 2” x 10” specimens to be cut from 22” pipe, 3 resins
- Planned duration ~1000 hrs; longer if needed



Prior SCG Tests

- Prior work (report 1022565) tested 10% deep scratches in tensile coupons and in pressurized pipes
  - Cracks in base material only (not in fusion zone)
- Tensile type tests
  - 8 Razor, 8 Designer, & 2 Control specimens
  - 95 C, 50%Sy
  - Bimodal resin (PENT > 10,000 hrs)
  - Objective was to develop method to obtain da/dt curves
    - Inconclusive results, were not able to accurately determine crack depth
  - Total test time was 5160 hrs (215 days)

Prior SCG Tests (continued)

- Pressurized pipe tests
  - Used 4” diameter SDR11 pipe
  - 3 types of flaws: Razor, “Designer”, Blended, + controls
  - 10% scratch, 30%, 40% and 50% S_y
  - Tests at 85 C and 95 C; 72 specimens total
  - Crack length = 1 x pipe diameter per ISO 13479 & ASTM F1474
  - Specimen length = 30”, 24” between end cap beads
  - Three PE 4710 materials
    - 1 Unimodal resin: PENT = 500 hrs
    - 2 bimodal resins: PENTs = 1500 hrs and 10,000 hrs
  - Tested to 10,000 hours or until failure
  - No on-line measurement of crack depth vs time

Prior SCG Tests (continued)

- Shifting of pressurized pipe test results
  - Two methods were utilized to shift test data to code allowable stresses at various temperatures
  - Popelar Shift Method of all 3 resins
    - Bi-directional shift enabling separate shifts for each test temperature
  - Rate Process Method for Resin A
    - 2 temperatures are needed, thus could only shift Resin A data
  - A comparison of Popelar and RPM methods for Resin A found RPM to be somewhat more conservative

Prior SCG Tests (continued)

- Example Shifts of Razor Notch to 60 C (140°F)

Prior SCG Tests (continued)

Estimated Life for a 10% Razor Crack in 4” Pipe at Code Maximum Stress

Shifted Data for Bimodal Materials

Temperature	Allowable Stress (psi)	Popelar Shift from 85°C (years) (Resin C – PENT = 10,000 hrs)	Popelar Shift from 95°C (years) (Resin B – PENT = 1500 hrs)
73°F	800	144,955	19,156
100°F	670	29,377	3896
140°F	500	4066	595
176°F	341	2504	549

Prior SCG Tests (continued)

Summary

- Data from cracked tensile tests was considered inconclusive
  - Creep tended to obscure correlations of crack depth to crack mouth opening
    - Also, depth varied across width
  - Data analysis continuing, conclusions could change
- Razor notches generally more severe
- Definite correlation between PENT rating and estimated life
- Data from 1500 hr and 10,000 hr PENT resins supported > 60 year life of a 4” SDR11 pipe with a 10% scratch
  - > 20 years at 176 F
- No failures at 30% Sy

New SCG Tests

- Objectives
  - Identify if crack growth is driven by nominal stress, ligament stress, or K_I
    - Data from specimens with multiple crack depths and stress levels will be needed
    - Crack length set where 2 methods to determine K_I intersect
  - Develop data to be able to determine an acceptable scratch depth for larger size pipes
  - Evaluate the effects of a scratch in the fusion zone
    - Also the effects of a blended out scratch in the fusion zone

New SCG Tests (continued)

- Plan
  - Test 3 conforming resins, focus on 2000 hr min PENT
    - Note: Resin C was used in prior tests, PENT = 10,000 hr
  - Razor cracks only
  - Test at 40%, 45%, 50% Sy
  - 1 temperature?; 90 C or 95 C; coordinate with NRC tests?
  - 3 pipe sizes: 4”, 8”, 16”
    - Larger diameters require very large tanks, severely limit number of specimens
  - 10,000 hr tests

New SCG Tests (continued)

Base Tests (8” and 16” Pipe)																												
K_I	Clear Pipe																		Fusion Joint Raw Crack						Fusion Joint – Blended Crack					
	50% Yield Stress						45% Yield Stress						40% Yield Stress						50% Yield Stress						50% Yield Stress					
	Resin	Size	SDR	No.	Crack Depth	Crack Len.	Resin	Size	SDR	No.	Crack Depth	Crack Len.	Resin	Size	SDR	No.	Crack Depth	Crack Len.	Resin	Size	SDR	No.	Crack Depth	Crack Len.	Resin	Size	SDR	No.	Crack Depth	Crack Len.
365	A	16	7	2	7%	40”	A	16	7	2	9%	32”	A	16	7	2	11%	29”	A	16	7	2	7%	40”	A	16	7	2	7%	40”
300	A	16	7	2	5%	49”	A	16	7	2	6.5%	38”	A	16	7	2	7.5%	38”	---	---	---	---	---	---	----	----	----	----	----	----
220	A	8	7	2	5%	26”	A	8	7	2	6.0%	23”	A	8	7	2	8%	18”	A	8	7	2	5%	26”	A	8	7	2	5%	26”
	Total			6			Total			6			Total			6			Total			4			Total			4		

Comparative Tests (4” Pipe)																								
Clear Pipe																								
K_I	45% Yield Stress Resin A												45% Yield Stress Resin B						45% Yield Stress Resin C					
	Wall thickness 1						Wall Thickness 2						Wall Thickness 1						Wall Thickness					
	Resin	Size	SDR	No.	Crack Depth	Crack Len.	Resin	Size	SDR	No.	Crack Depth	Crack Len.	Resin	Size	SDR	No.	Crack Depth	Crack Len.	Resin	Size	SDR	No.	Crack Depth	Crack Len.
220	A	4	7	3	11%	8”	A	4	9	3	12%	6.5”	B	4	9	3	11%	8”	C	4	9	3	11%	8”
	Total			3			Total			3			Total			3			Total			3		