PPI
PENT TEST INVESTIGATION

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Foreword

This report was developed and published with the technical help and financial support of the members of the PPI (Plastics Pipe Institute, Inc.). The members have shown their interest in quality products by assisting independent standards-making and user organizations in the development of standards, and also by developing reports on an industry-wide basis to help engineers, code officials, specifying groups, and users.

The purpose of this technical note is to provide general information on use of the PENT test (ASTM F1473) when conducted on samples molded from PE pellets and also when conducted on extruded solid wall pipe with the samples cut in the axial direction.

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This Technical Note, TN-21, was first issued in 2000 and was revised in January 2013 and reformatted in July 2019.

Table of Contents

List of Tables

PENT TEST INVESTIGATION

1.0 SCOPE

The purpose of this project was to evaluate applicability of the PENT test (ASTM F 1473 “Standard Test Method for Notch Tensile Test to Measure the Resistance to Slow Crack Growth of Polyethylene Pipes and Resins”) for slow crack growth determination of polyethylene (PE) resins and extruded solid wall pipe. The PENT method was also evaluated as a quality control (QC) indicator for extruded pipe. PENT has been identified as a potential test protocol to supplement 80°C hydrostatic testing of PE pipe resins.

The evaluation included the compression molded plaques under slow cooled condition that were further prepared by machining and band sawing, and longitudinal samples cut directly from the wall of extruded pipe along the pipe direction. Testing included numerous laboratories and several commercially available medium density gas pipe resins. The resins chosen were 1st generation resins with significant long-term field experience.

A number of extrusion conditions were also evaluated to determine if the PENT test has applicability as an extrusion quality monitor.

2.0 RESULTS

As shown in Attachment #1, molded plaque specimens that were further prepared by machining produced the most consistent and reproducible results. Molded plaques prepared by band sawing yielded similar average test times but produced significant data scatter and a standard deviation of results about twice that for machined samples.

Attachment #2 summarizes testing of samples cut longitudinally (axial direction) from the wall of pipe, which yielded widely scattered and non-reproducible results. Sample preparation and direction of sample loading for pipe samples, compared to polymer orientation, appears to handicap PENT applicability to pipe.

PPI also conducted PENT and 80°C sustained pressure testing (ASTM D1598) on pipe samples prepared with several changes in extrusion variables (see Attachment #4). These tests showed there is no apparent correlation between the PENT results (cut from axial direction) and those of traditional 80°C hydrostatic testing of pipe (see Attachment #3).

No significant difference between samples loaded with level-arm type or air-cylinder type test apparatuses was indicated.

3.0 SUMMARY

Based on the results of this evaluation, it appears that the PENT test as performed on molded plaques of PE further prepared by machining yields results that are correlatable to 80°C hydrostatic testing of PE pipe. However, post preparation of molded plaque samples by band sawing produced a considerable increase in data scatter.

Results of samples cut from extruded pipe (axial direction) indicate that there is no correlation between the PENT results and those of 80°C hydrostatic testing. A number of causal factors are hypothesized including difficulty in sample preparation and direction of notching relative to polymer orientation; however, no further work is planned to evaluate potential factors for reductions in data scatter. Slow crack growth resistance is significantly increased when the notch is perpendicular to the polymer orientation direction, while decreased when the notch is parallel to the polymer orientation direction. PENT evaluation of pipe produced with various changes in extrusion variables produced nearly the opposite results of 80°C hydrostatic tests. Note that hydrostatic tests measure the pipe strength in the hoop direction, while PENT tests using longitudinally cut specimens measure the slow crack growth resistance in the pipe direction under axial loading. PPI did not conduct PENT testing on the same pipe samples cut in the circumferential direction.

4.0 RECOMMENDATIONS

Based on the results of this evaluation, the task group concluded that the PENT test (ASTM F1473) may be used to compare the relative slow crack growth resistance of PE materials when samples are prepared from molded plaques. The task group further concluded that the PENT test could not be used as a QC test for PE pipe when samples are cut in the axial direction. Due to the difference in measured slow crack growth property relative to polymer orientation directions, there appears to be an inverse correlation between PENT values obtained from PE pipe samples cut in the axial direction with long-term 80°C sustained pressure testing (ASTM D1598) performed on the same pipe samples.

Appendix

Phase I – PENT Test Investigation

Scope: Testwork was initiated to evaluate newly issued Tech Team PENT Testers.
Sample was provided as compounded black resin.
Nominal resin properties are 0.09 melt flow (190/2.16), 9.4 (190/21.6) and 0.954 density.
Data evaluation included comparison of specimen measurement, specimen molding, and notching. Equipment operators for each lab were not varied for the course of the study.

Table A.1 – Attachment 1

	Lab A	**Lab B**	**Lab B**
Pent Tester	Tech Team	Tech Team	Tech Team
Load Type	Air Cylinder	Lever Arm	Lever Arm
No. of Stations	12	20	20
Temp Verified	Yes	Yes	Yes
Notcher	Dr. Brown Mfg	Dr. Brown Mfg	Dr. Brown Mfg
Conditions	ASTM F1473	ASTM F1473	ASTM F1473
Exceptions	None	None	None
Sample Prep	Mold & Machined	Mold & Band Saw	Mold & Machined
No. of Specimens	68	47	38
PENT, hrs	20.6	34.2	26.9
Std Dev, hrs	1.9	7.3	3.4
Std Dev, %	9.2%	21.3%	12.6%
Between Lab Variability	STD Dev, hrs	4.4	
(Machined Specimens)	STD Dev, %	19.0%	

Conclusions:

1. Machining improved accuracy of sample measurement thereby improving data.
2. Minimal difference noted between air cylinder and lever arm testing.
3. Noted that dimensions varied with time.

Phase II - PENT Testing

Table A.2 – Attachment 2

Scope: Pipe Samples were produced from the same compounded resin in Phase I for evaluation of processing conditions.
The pipe samples were 2" IPS DR11 produced by a single manufacturer and supplied to all participating test laboratories.
The test specimens were cut axially from the pipe to meet geometry criteria. The notch was transverse to the axial.
The process conditions varied draw down and cooling temperature.

Sample		LAB C	LAB D	LAB A	LAB E	LAB B	LAB F	LAB G	Average
	PENT Tester	Tech Team	Tech Team	Tech Team	Dr. Brown Mfg	Tech Team	Dr Brown Mfg	Tech Team	
	Load Type	Lever Arm	Air Cylinder	Air Cylinder	Lever Air	Lever Arm	Lever Arm		
	No. of Stations	12	12	12	12	20	12	12	
	Temp Verified	Yes	No	Yes	Yes	Yes	Yes		
	Notcher	Dr Brown Mfg	Tech Team	Dr. Brown Mfg	Dr. Brown Mfg	Dr. Brown Mfg	Dr. Brown Mfg		
	Conditions	ASTM F1473	ASTM F1473	ASTM F1473	ASTM F1473	ASTM F1473	ASTM F1473	ASTM F1473	
	Exceptions	No	No	No	No	Flat Spec Back	Fixtured to Notch		
	Sample Specimen	2" DR11	2" DR11	2" DR11	2" DR11	2" DR11	2" DR11	2" DR11	
A	No.of Specimes	6	11	2	12	1	2	6	
	PENT, hrs	137.5	118.7	327.5	195.4	232.0	162.0	203.5	196.6
	Std Dev, hrs	15.6	43.3	275.1	76.2		22.6	30.5	69.8
	Std Dev, %	11.4%	36.5%	84.0%	39.0%		14.0%	15.0%	35.5%
B	No. of Specimens	6	11	2	12	1	2	3	
	PENT, hrs	93.6	98.9	155.0	83.7	192.0	105.1	118.0	121.6
	Std Dev, hrs	10.1	36.6	94.8	35.6		20.4	35.2	40.5
	Std Dev, %	10.8%	37.0%	61.1%	42.5%		19.4%	29.8%	33.3%
C	No. of Specimens	7	11	2	12	1	2		
	PENT, hrs	79.6	92.8	92.5	74.2	102.0	122.6		93.9
	Std Dev, hrs	37.0	36.3	13.4	24.1		9.1		17.2
	Std. Dev, %	46.5%	39.2%	14.5%	32.5%		7.4%		18.3%
C	No. of Specimens	6	11	2	12	1	2		
	PENT, hrs	103.3	128.0	143.0	89.3	105.0	122.8		115.2
	Std Dev, hrs	16.2	54.5	5.7	23.6		9.1		19.6
	Std Dev, %	15.7%	42.6%	4.0%	26.5%		7.4%		17.0%
E	No. of Specimens	6	11	2	12	1	2	3	
	PENT, hrs	96.9	104.7	111.0	89.3	105.0	98.0	131.3	100.8
	Std Dev, hrs	16.7	42.1	15.6	23.6		11.7	27.7	7.7
	Std Dev, %	17.3%	40.2%	14.0%	26.5%		11.9%	21.1%	7.6%
H	No. of Specimens	6	11	2	12	1			
	PENT, hrs	130.2	205.8	158.5	119.6	58.0			112
	Std Dev, hrs	10.1	77.6	17.7	24.7				73.2
	Std Dev, %	7.7%	37.7%	11.2%	20.6%				66.4%
I	No. of Specimens	6	11	2	12	1			
	PENT, hrs	149.1	211.3	153.0	146.5	78			167.6
	Std Dev, hrs	14.8	110.8	14.1	31.7				27.5
	Std Dev, %	9.9%	52.4%	9.2%	21.6%				16.4%

Conclusions

1. Data variability increased for most laboratories.
2. A large source of the variability is believed to be the difficulty in precisely notching a curved specimen without a fixture.
3. A potential source of variability may be the sample measurement of a curved specimen.

Phase III - Pipe Processing - 80°C Hoop Strength

Table A.3 – Attachment 3

Sample		Spec 1	Spec 2	Spec 3	LAB A	LAB B
A	No.of Specimens				3	1
	80°C HS, hrs	841	879	1075	926	1543
	Std Dev, hrs				126	
	Std Dev, %				14%	
B	No. of Specimens				3	1
	80°C HS, hrs	460	1349	2111	1094	926
	Std Dev, hrs				826	
	Std Dev, %				76%	
C	No. of Specimens				3	1
	80°C HS, hrs	978	1388	1868	1364	1246
	Std Dev, hrs				445	
	Std. Dev, %				33%	
C	No. of Specimens				3	1
	80°C HS, hrs	770	1201	1319	1068	1297
	Std Dev, hrs				289	
	Std Dev, %				27%	
E	No. of Specimens				3	1
	80°C HS, hrs	1635	2834	2636	2303	1487
	Std Dev, hrs				643	
	Std Dev, %				28%	
H	No. of Specimens				3	1
	80°C HS, hrs	279	790	1593	705	1628
	Std Dev, hrs				662	
	Std Dev, %				94%	
I	No. of Specimens				3	1
	80°C HS, hrs	886	1019	1306	1056	1802
	Std Dev, hrs				215	
	Std Dev, %				20%	

Phase III – Pipe Processing versus PENT and Hoop Strength

Table A.4 – Attachment 4

Attachment 4

Phase III - Pipe Processing versus PENT and Hoop Strength

Scope

Pipe Samples were produced from the same compounded resin in Phase I for evaluation of processing conditions.
The pipe samples were produced by a single manufacturer and submitted to all participating test laboratories.
Pent data from Lab C was used as a basis as it is most complete with minimum variability.
Lab A 80C data was used as a basis as it had the minimum variability.
The process conditions are shown below.
Design of Experiments was three factor, full factorial with initial point replication.
Two data points could not be generated due to process limitation.

	Wall Draw Down	Dia Draw Down	Cooling Rate
Low	24%	15%	62F
High	24%	54%	83F

Condition	Wall Draw Down	OD Draw Down		Number	PENT, h	Std Dev, %	Number	80°C HS, h	Std Dev, %
A	High	High	High	6	137.5	11.4%	3	926	14%
B	Low	Low	Low	6	93.6	10.8%	3	1094	76%
C	Low	Low	High	6	79.6	46.5%	3	1364	33%
D	High	Low	Low	6	103.3	15.7%	3	1068	27%
E	High	Low	High	6	96.9	17.3%	3	2303	28%
F	Low	High	Low	Unable to Produce Pipe at This Condition					
G	Low	High	High	Unable to Produce Pipe at This Condition					
H	High	High	Low	6	130.2	7.7%	3	705	94%
I	High	High	High	6	149.1	9.9%	3	1056	20%

Statistics	Average	112.9	17.0%		1217	42%
	Std Dev, %	23%			43%	
	Replication	108%			114%	

Affect	Reduced OD Draw Down	Inverted Major	Major
	Reduced OD & Wall Draw Down	Inverted Major	Major
	Reduced Cooling Rate	Negligible	Minor

Conclusions

1. Good Replication of Initial Conditions
2. Notching of Pipe Specimens transverse to axial reversed the expected relations to draw down and cooling rate.
3. Draw down provided a mojor affect under both measures.
4. Unable to individually quantify wall draw down affect or measure interaction to diameter draw down.
5. Cooling affect not significant for these production runs.