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Final Report on P301 (Natural)

PE-pipe Grade Resin Manufactured by Korea Petrochemical Ind. Co., Ltd.

RT11-00811 (Status: Confidential)

NOVEMBER 26, 2012

Plastic Reliability Center

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Signed by

K.J.Lee

Kyungjae Lee
General Manager

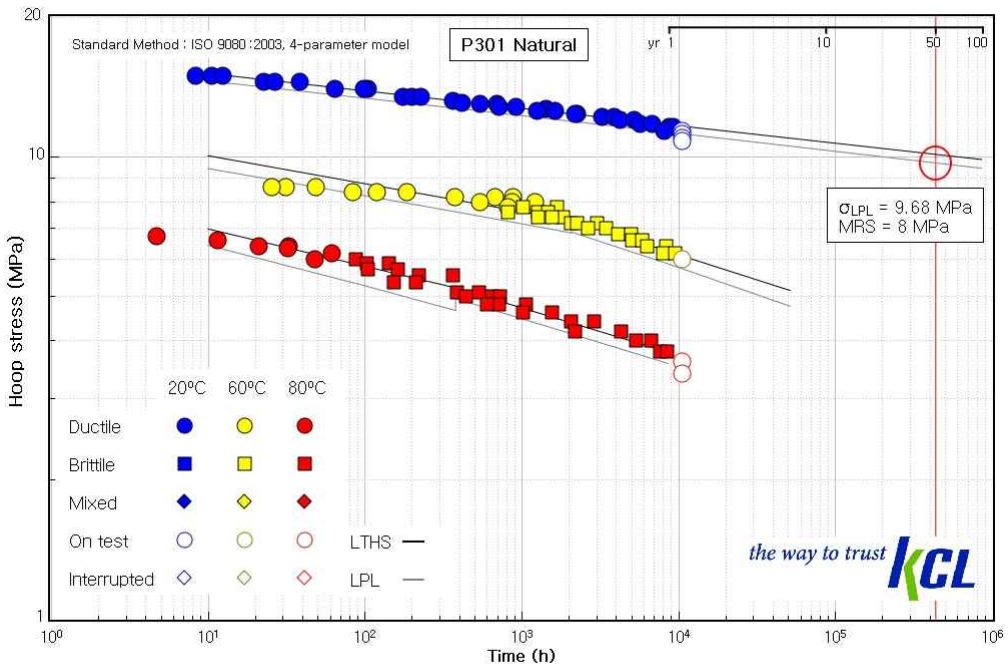
NOVEMBER 26. 2012

CONTENTS

LONG-TERM HYDROSTATIC STRENGTH EVALUATION ON P301 PE-PIPE GRADE RESIN MANUFACTURED BY KOREA PETROCHEMICAL IND. CO., LTD.

ABSTRACT

In order to obtain the most reliable σLPL value at 50-Years at 20℃, the Full Long-Term Hydrostatic Strength Evaluation on the pipe grade resin is running at various test temperatures at KCL Plastic Reliability Center in Korea.



Ductile failure Log(t) = -90.377 + 35953.467 · 1/T + 56.731 · Log(σ) - 24403.643 · Log(σ)/T

Brittle failure Log(t) = -18.893 + 10045.399 · 1/T - 18.443 · Log(σ) + 3071.834 · Log(σ)/T

With respect to the valid ISO document, a long-term strength value of 9.68 MPa at 50-Years at 20 ℃ (97.5 % LCL) has been calculated. According to the valid ISO 12162, this value clearly satisfies the classification of MRS of 8 MPa at 50-Years at 20 ℃.

1. GENERAL INFORMATION

1.1 Material Information

A basic information for the material and evaluated pipes is summerized as follows.

Material name	P301
Pipe colour	Natural
Type of material	PE
Nomanal dimension	∅32 mm x 3 mm
Length of specimen	400 mm
Manufacturer	Korea Petrochemical Ind. Co., Ltd.

1.2 Experimental Information

A basic information for the experiment is summerized as follows.

Method	ISO 1167-1 / -2
Temperature	20 ℃, 60 ℃, 80 ℃
Type of End-cap	Type A, Stainless steel
Internal medium	Water
External medium	water
Conditioning time	3 h

2. RESULT FROM HYDROSTATIC PRESSURE TESTING

The detailed result from hydrostatic pressure testing is presented in Appendix 1.

Temp	Total No. of pipes	Test Duration > 7 000 h	Test Duration > 9 000 h	Pressure levels
20	32	4	2	16
60	36	5	3	14
80	35	4	2	17
Requirement[1)]	≥ 30	4	1	5

1) According to paragraph 4.2.1 in ISO 9080.

3. EVALUATION RESULT ACCORDING TO ISO 9080

The general 4-parameter model used in ISO 9080 as follows

$$Log(t) = C_1 + C_2 \cdot \frac{1}{T} + C_3 \cdot Log(\sigma) + C_4 \cdot \frac{Log(\sigma)}{T} + e$$

where

$C_1,\ C_2,\ C_3,\ C_4$	parameters used in this model
t	time to failure, h
T	Temperature, K
σ	Hoop stress, MPa
e	error variable

The regression analysis is based on the 4-Parameter Model, while the probability level of C3 $\leq$ 0.05 and the test of fit shows a higher level of reliability than the analysis applied with the 3-Parameter Model.

3.1. Estimation

Type A Failure

Residual variance	=	0.041739
Number of points	=	50
Number of parameters	=	4
Number of degrees of freedom	=	46

Parameter estimates

	Value	Std. Error	t value	Pr (> |t|)
C1	-90.377	5.623	-16.074	0.000
C2	35953.467	1811.968	19.842	0.000
C3	56.731	6.044	9.386	0.000
C4	-24403.643	1844.750	-13.229	0.000

Test of fit : Pr[F(22;24) > 5.278] = 0.000

Type B Failure

Residual variance	=	0.012291
Number of points	=	52
Number of parameters	=	4
Number of degrees of freedom	=	48

Parameter estimates

	Value	Std. Error	t value	Pr (> |t|)
C1	-18.893	9.833	-1.921	0.061
C2	10045.399	3444.571	2.916	0.005
C3	-18.443	12.118	-1.522	0.135
C4	3071.834	4230.337	0.726	0.471
Test of fit : Pr[F(20;28) > 1.224] = 0.305				

3.2. Prediction

Type A Failure

Prediction (hour)

Time (hr) / Temp (℃)	1	10	100	1 000	10 000	100 000
20	16.482	15.111	13.854	12.702	11.645	10.676
60	11.533	10.032	8.727	7.592	-	-
80	8.395	6.969	5.786	-	-	-

Lower Prediction Limit (hour), Confidence Level (one sided) = 0.975

Time (hr) / Temp (℃)	1	10	100	1 000	10 000	100 000
20	15.842	14.555	13.359	12.246	11.212	10.254
60	10.729	9.410	8.222	7.149	-	-
80	7.720	6.421	5.250	-	-	-

Prediction (year)

Time (yr) / Temp (℃)	0.5	1	10	50
20	12.013	11.703	10.730	10.098
60	-	-	-	-
80	-	-	-	-

Lower Prediction Limit (year), Confidence Level (one sided) = 0.975

Time (yr) / Temp (℃)	0.5	1	10	50
20	11.574	11.270	10.307	9.677
60	-	-	-	-
80	-	-	-	-

Type B Failure

Prediction (hour)

Time (hr) / Temp (℃)	1	10	100	1 000	10 000	100 000
20	-	-	-	-	-	-
60	-	-	-	-	6.126	4.772
80	-	-	-	4.703	3.713	2.932

Lower Prediction Limit (hour), Confidence Level (one sided) = 0.975

Time (hr) / Temp (℃)	1	10	100	1 000	10 000	100 000
20	-	-	-	-	-	-
60	-	-	-	-	5.753	4.377
80	-	-	-	4.457	3.507	2.749

Prediction (year)

Time (yr) / Temp (℃)	0.5	1	10	50
20	-	-	-	-
60	6.699	6.214	4.841	4.066
80	4.041	3.764	2.972	2.519

Lower Prediction Limit (year), Confidence Level (one sided) = 0.975

Time (yr) / Temp (℃)	0.5	1	10	50
20	-	-	-	-
60	6.319	5.842	4.448	3.654
80	3.823	3.556	2.788	2.348

3.3. Extrapolation limits for Polyolefins polymers

Extrapolation limits : Tmax = 60 (℃), tmax = 9 277.47 (hour)				
TPred	Delta T	Ke	tlim (hour)	tlim (year)
20	40	50	463 873.53	52.95

Extrapolation limits : Tmax = 80 (℃), tmax = 8 585.56 (hour)				
TPred	Delta T	Ke	tlim (hour)	tlim (year)
20	60	100	858 555.66	98.01
60	20	6	51 513.34	5.88

3.4. Knee position

Temperature	Stresss MPa	Time h
60	7.26	2081.00
80	5.19	379.98

4. CLASSIFICATION ACCORDING TO ISO 12162

Regarding the before written Evaluation result - σLPL value of 9.68 MPa at 20 ℃ and 50 years, the PE pipe material P301 (Natural) is classified by MRS of 8 MPa according to ISO 12162.

Appendix 1-1

Manufacturer	: KOREA PETROCHEMICAL IND. CO., LTD.	Test Method	: ISO 1167-2
Material	: PE	Type of End cap	: Type A
Type	: Pipe	Temperature	: 20 ℃
Source	: KOREA PETROCHEMICAL IND. CO., LTD.	Environment	: Water-water
Nominal size	: Ø32x3	conditioning time	: 3 h
Specimens tested	: 39	Date	: Jul 26, 2012

Specimen code	Minimum Wall Thickness (mm)	Average Outside Diameter (mm)	Line Pressure (MPa)	Hoop Stress (MPa)	Test Duration (h)	Failure Mode / Status
105	*3.10*	*32.30*	*3.185*	*15.00*	*8.36*	*Ductile*
66	3.07	32.30	3.151	15.00	10.54	Ductile
112	3.04	32.30	3.117	15.00	12.37	Ductile
101	3.06	32.30	3.035	14.50	22.41	Ductile
102	3.09	32.30	3.068	14.50	26.59	Ductile
103	3.02	32.30	2.991	14.50	38.48	Ductile
110	3.02	32.30	2.888	14.00	64.07	Ductile
106	3.05	32.30	2.920	14.00	103.52	Ductile
8	3.08	32.30	2.951	14.00	98.74	Ductile
80	3.09	32.30	2.856	13.50	175.06	Ductile
109	3.06	32.30	2.826	13.50	199.43	Ductile
113	3.05	32.30	2.815	13.50	227.65	Ductile
46	3.03	32.30	2.733	13.20	364.61	Ductile
39	3.09	32.30	2.772	13.10	414.04	Ductile
21	3.07	32.30	2.731	13.00	538.40	Ductile
64	3.05	32.30	2.711	13.00	692.51	Ductile
51	3.06	32.30	2.679	12.80	713.16	Ductile
69	3.03	32.30	2.650	12.80	915.59	Ductile
88	3.01	32.30	2.610	12.70	1431.50	Ductile
30	3.02	32.30	2.599	12.60	1246.65	Ductile
73	3.07	32.30	2.647	12.60	1624.19	Ductile
58	3.07	32.30	2.605	12.40	2244.21	Ductile
29	3.06	32.30	2.595	12.40	2179.20	Ductile
13	3.02	32.30	2.517	12.20	3240.69	Ductile
25	3.08	32.30	2.572	12.20	3865.75	Ductile
54	3.04	32.30	2.494	12.00	4194.93	Ductile
14	3.03	32.30	2.484	12.00	5186.72	Ductile
33	3.01	32.30	2.425	11.80	5664.89	Ductile
72	3.03	32.30	2.443	11.80	6715.05	Ductile
93	3.09	32.30	2.454	11.60	8627.44	Ductile

italic character : excluded in the ISO 9080 evaluation

Appendix 1-1 Continued

Specimen code	Minimum Wall Thickness (mm)	Average Outside Diameter (mm)	Line Pressure (MPa)	Hoop Stress (MPa)	Test Duration (h)	Failure Mode / Status
35	3.01	32.30	2.384	11.60	9156.47	Ductile
34	3.04	32.30	2.369	11.40	8092.60	Ductile
87	3.07	32.30	2.395	11.40	10500	On test
108	*3.09*	*32.30*	*2.370*	*11.20*	*10500*	*On test*
94	*3.04*	*32.30*	*2.327*	*11.20*	*10500*	*On test*
104	*3.02*	*32.30*	*2.269*	*11.00*	*10500*	*On test*
100	*3.10*	*32.30*	*2.336*	*11.00*	*10500*	*On test*
107	*3.09*	*32.30*	*2.285*	*10.80*	*10500*	*On test*
111	*3.01*	*32.30*	*2.220*	*10.80*	*10500*	*On test*

italic character : excluded in the ISO 9080 evaluation

Appendix 1-2

Manufacturer	: KOREA PETROCHEMICAL IND. CO., LTD.	Test Method	: ISO 1167-2
Material	: PE	Type of End cap	: Type A
Type	: Pipe	Temperature	: 60 ℃
Source	: KOREA PETROCHEMICAL IND. CO., LTD.	Environment	: Water-water
Nominal size	: Ø32x3	conditioning time	: 3 h
Specimens tested	: 36	Date	: Jul 04, 2012

Specimen code	Minimum Wall Thickness (mm)	Average Outside Diameter (mm)	Line Pressure (MPa)	Hoop Stress (MPa)	Test Duration (h)	Failure Mode / Status
95	3.06	32.30	1.800	8.60	31.28	Ductile
62	3.00	32.30	1.761	8.60	25.26	Ductile
79	3.04	32.30	1.787	8.60	48.43	Ductile
53	3.02	32.30	1.733	8.40	118.70	Ductile
18	3.08	32.30	1.771	8.40	83.42	Ductile
81	3.04	32.30	1.745	8.40	184.48	Ductile
6	3.03	32.30	1.698	8.20	873.10	Ductile
60	3.04	32.30	1.704	8.20	371.55	Ductile
5	3.05	32.30	1.710	8.20	672.44	Ductile
9	3.03	32.30	1.656	8.00	860.01	Ductile
89	3.08	32.30	1.687	8.00	1210.53	Ductile
37	3.04	32.30	1.662	8.00	539.40	Ductile
38	3.00	32.30	1.597	7.80	808.79	Ductile
75	3.06	32.30	1.633	7.80	1014.81	Brittle
97	3.08	32.30	1.644	7.80	1672.64	Brittle
3	3.03	32.30	1.573	7.60	1265.27	Brittle
52	3.03	32.30	1.573	7.60	1465.40	Brittle
71	3.03	32.30	1.573	7.60	814.03	Brittle
45	3.09	32.30	1.566	7.40	1824.27	Brittle
23	3.05	32.30	1.543	7.40	1554.13	Brittle
22	3.09	32.30	1.566	7.40	1265.10	Brittle
16	3.07	32.30	1.512	7.20	3011.08	Brittle
96	3.02	32.30	1.485	7.20	2054.78	Brittle
43	3.07	32.30	1.512	7.20	2244.21	Brittle
27	3.09	32.30	1.481	7.00	2651.59	Brittle
50	3.08	32.30	1.476	7.00	3442.87	Brittle
41	3.04	32.30	1.413	6.80	4099.83	Brittle
20	3.02	32.30	1.403	6.80	4963.01	Brittle
15	3.09	32.30	1.396	6.60	5012.57	Brittle
99	3.06	32.30	1.381	6.60	5812.60	Brittle

italic character : excluded in the ISO 9080 evaluation

Appendix 1-2 Continued

Specimen code	Minimum Wall Thickness (mm)	Average Outside Diameter (mm)	Line Pressure (MPa)	Hoop Stress (MPa)	Test Duration (h)	Failure Mode / Status
28	3.05	32.30	1.335	6.40	6311.45	Brittle
63	3.06	32.30	1.340	6.40	8312.09	Brittle
2	3.09	32.30	1.312	6.20	7941.83	Brittle
92	3.09	32.30	1.312	6.20	9443.62	Brittle
7	3.02	32.30	1.238	6.00	10500	On test
65	3.02	32.30	1.238	6.00	10500	On test

italic character : excluded in the ISO 9080 evaluation

Appendix 1-3

Manufacturer	: KOREA PETROCHEMICAL IND. CO., LTD.	Test Method	: ISO 1167-2
Material	: PE	Type of End cap	: Type A
Type	: Pipe	Temperature	: 80 ℃
Source	: KOREA PETROCHEMICAL IND. CO., LTD.	Environment	: Water-water
Nominal size	: Ø32x3	conditioning time	: 3 h
Specimens tested	: 38	Date	: Jul 04, 2012

Specimen code	Minimum Wall Thickness (mm)	Average Outside Diameter (mm)	Line Pressure (MPa)	Hoop Stress (MPa)	Test Duration (h)	Failure Mode / Status
91	*3.06*	*32.30*	*1.413*	*6.75*	*4.67*	*Ductile*
90	3.01	32.30	1.357	6.60	11.43	Ductile
61	3.08	32.30	1.349	6.40	32.42	Ductile
56	3.06	32.30	1.340	6.40	21.07	Ductile
12	3.02	32.30	1.310	6.35	32.00	Ductile
24	3.03	32.30	1.284	6.20	61.63	Ductile
55	3.04	32.30	1.247	6.00	87.23	Brittle
44	3.04	32.30	1.247	6.00	47.91	Ductile
86	3.08	32.30	1.244	5.90	103.10	Brittle
84	3.00	32.30	1.208	5.90	141.25	Brittle
83	3.07	32.30	1.197	5.70	104.71	Brittle
68	3.01	32.30	1.172	5.70	161.62	Brittle
31	3.03	32.30	1.149	5.55	219.03	Brittle
11	3.06	32.30	1.162	5.55	362.72	Brittle
17	3.07	32.30	1.124	5.35	210.72	Brittle
48	3.05	32.30	1.116	5.35	152.39	Brittle
47	3.02	32.30	1.052	5.10	382.09	Brittle
76	3.04	32.30	1.060	5.10	531.53	Brittle
26	3.07	32.30	1.050	5.00	439.08	Brittle
82	3.03	32.30	1.035	5.00	643.44	Brittle
59	3.01	32.30	1.028	5.00	723.73	Brittle
1	3.02	32.30	0.990	4.80	713.16	Brittle
74	3.07	32.30	1.008	4.80	599.13	Brittle
98	3.09	32.30	1.016	4.80	1060.55	Brittle
77	3.03	32.30	0.952	4.60	1013.84	Brittle
49	3.00	32.30	0.942	4.60	1554.13	Brittle
36	3.04	32.30	0.914	4.40	2054.78	Brittle
4	3.05	32.30	0.918	4.40	2881.21	Brittle
32	3.03	32.30	0.870	4.20	2179.10	Brittle
40	3.00	32.30	0.860	4.20	4284.64	Brittle

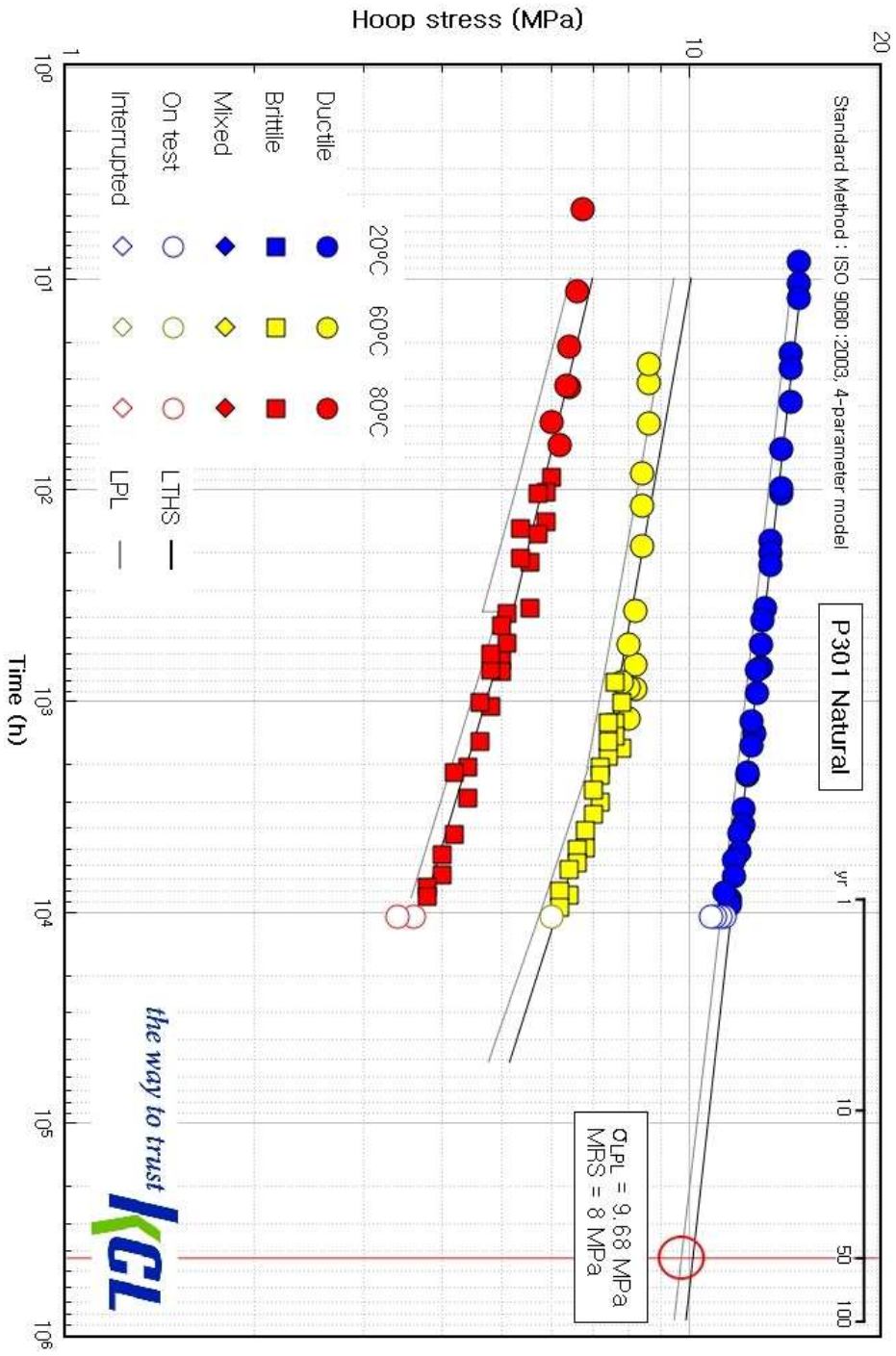
italic character : excluded in the ISO 9080 evaluation

Appendix 1-3 Continued

Specimen code	Minimum Wall Thickness (mm)	Average Outside Diameter (mm)	Line Pressure (MPa)	Hoop Stress (MPa)	Test Duration (h)	Failure Mode / Status
78	3.08	32.30	0.843	4.00	5314.08	Brittle
10	3.04	32.30	0.831	4.00	6658.92	Brittle
19	3.01	32.30	0.781	3.80	7595.14	Brittle
70	3.01	32.30	0.781	3.80	8366.12	Brittle
67	3.06	32.30	0.753	3.60	10500	On test
57	3.02	32.30	0.743	3.60	10500	On test
85	*3.02*	*32.30*	*0.701*	*3.40*	*10500*	*On test*
42	*3.04*	*32.30*	*0.706*	*3.40*	*10500*	*On test*

italic character : excluded in the ISO 9080 evaluation

Appendix 2-1.


Hoop stress (MPa)
Time (h)
Standard Method : ISO 9080:2003, 4-parameter model
P301 Natural
yr 1
10
50
100
20
10
1
10^0
10^1
10^2
10^3
10^4
10^5
10^6
20°C
60°C
80°C
Ductile
Brittle
Mixed
On test
Interrupted
LTHS
LPL
σ_{LPL} = 9.68 MPa
MRS = 8 MPa
the way to trust KCL

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