EXOVA REPORT

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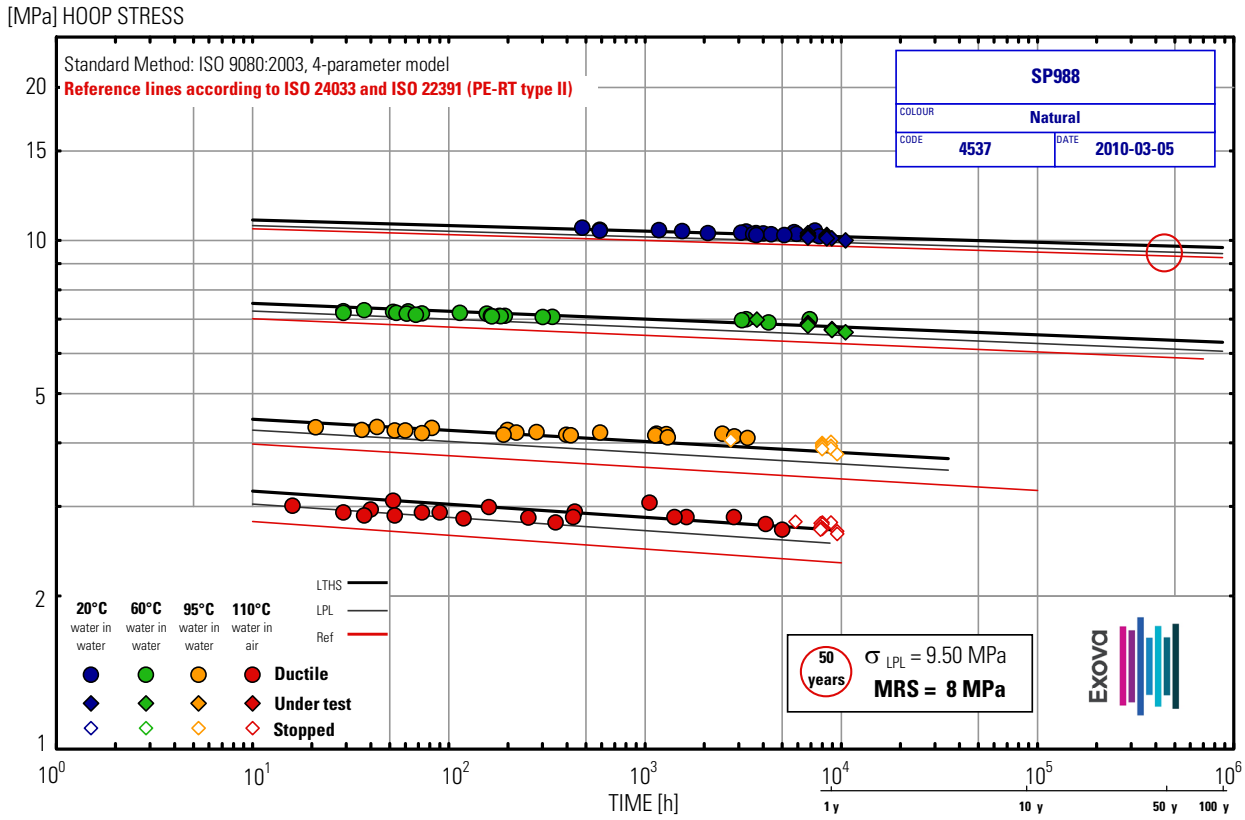
DETERMINATION OF THE LONG-TERM HYDROSTATIC STRENGTH

ISO 9080:2003-evaluation of the PE-RT pipe grade SP 988 Natural from LG Chem, Ltd.

Mattias SVEDBERG



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DETERMINATION OF THE LONG-TERM HYDROSTATIC STRENGTH ISO 9080:2003-evaluation of the PE-RT pipe grade SP 988 Natural from LG Chem, Ltd

ABSTRACT

The aim of this project was to determine the long term hydrostatic strength of the PE-RT pipe grade SP 988 Natural according to ISO 9080 and then MRS-classify it according to ISO 12162.

The ISO 9080-evaluation of the pipe grade gives the following strength values at 20°C and 50 years;

T	Time	σ_{LPL}	σ_{LTHS}
20°C	50 yrs	9.50 MPa	9.76 MPa
70°C	50 yrs	5.54 MPa	5.30 MPa

By its LPL value of 9.50 MPa at 20°C and 50 years the PE-RT pipe grade SP 988 Natural from LG Chem, Ltd. has a minimum required strength (MRS) of 8 MPa and is thereby designated PE-RT 80 according to ISO 12162:1995.

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1 EVALUATED PIPE GRADE

A short presentation of the evaluated pipe grade is presented below and detailed information is given in Appendix B.

Table 1 *Evaluated pipe grade*

Trade name	SP 988
Pipe colour	Natural
Pipe material	PE-RT
Nominal pipe dimension	16 x 2 mm
EXOVA internal code	4537

2 EXPERIMENTAL PROCEDURE

The hydrostatic pressure testing is performed at Exova according to ISO 1167:2006. The pressure testing at 20, 60 and 95°C is performed using deionised water on the inside and on the outside of the pipe specimens. At 110°C air is used on the outside. The accuracy for temperature[1] and pressure[1] is better than ±1°C and +2/-1% respectively. The measurements of the wall thickness[1] are accurate within ±0.01 mm and the diameter[1] within ±0.1 mm.

3 RESULTS FROM THE HYDROSTATIC PRESSURE TESTING

The results obtained from the hydrostatic pressure testing are presented in Appendix B and shown in Appendix C. Table 2 gives a summary of the observations.

Table 2 *Summary of the results from the hydrostatic pressure testing*

T	Total no of samples [1]	Failed samples [1]	Ongoing samples [1]	Stopped samples [1]	Longest failure time [h]	Longest test time [h]
20°C	50	24	12	14	7 729	10 502
60°C	58	31	8	19	6 911	10 502
95°C	42	23	0	19	3 330	9 528
110°C	53	26	0	27	4 996	9 528

[1] The expanded uncertainty of measurement has been calculated as the standard uncertainty of measurement multiplied by the coverage factor K=2, which for a normal distribution corresponds to a coverage probability of approximately 95%. The standard uncertainty of measurement has been determined in accordance with EA Publication EA-4/16:2003 and is documented at EXOVA.

4 ISO 9080-EVALUATION

The ISO 9080-evaluation consists of multiple linear regression analysis (MLR) on the stress rupture data obtained at the different test temperatures. The MLR is performed using the latest version of the software Pipeson Analyzer from Pipeson.

The ISO 9080 also includes extrapolation factors that determine to what times we can extrapolate at each temperature. The maximum extrapolation time is 100 years.

4.1 General model for the regression analysis according to ISO 9080

The general 4-parameter model used in ISO 9080 is the following:

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

where

C_1 *to* C_4	*parameters used in this model*	
t	*time to failure*	*[h]*
T	*Temperature*	*[K]*
σ	*Hoop stress*	*[MPa]*
e	*error variable*	*Laplace-Gaussian distribution, with zero mean and constant variance (the errors are assumed to be independent)*

The 4-parameter model shall be reduced to a 3-parameter model if the probability level of C_3 is greater than 0.05. i.e. $C_3 = 0$.

5 RESULTS FROM THE ISO 9080 EVALUATION

The diagram in Appendix C.2 shows the observations and lines for σ_{LPL} and σ_{LTHS} for the selected analysis.

5.1 Comments on selecting the data set for ISO 9080

- Data points equal to and below 179 h at 20°C was excluded from the analysis in accordance with paragraph 4.2.3 in ISO 9080.
- Knees were detected at 20, 60 and 95°C, however the knee detections were ignored since the knees were caused by ongoing samples and finally only ductile failures have been observed. Therefore the data types were manually changed from 'B' to 'A'.

5.2 Distribution of stress rupture data

Table 3 presents the distribution of observations for the data set that was used in the ISO 9080-evaluation.

Table 3 *Distribution of the stress rupture data included in the ISO 9080 evaluation*

T	Samples				Distribution		Pressure levels	Excluded samples[3)]
	Total	Failed	Ongoing	Stopped	>7 000 h	>9 000 h		
20°C	30	18	12	0	9	1	4	0
60°C	30	22	8	0	4	1	6	0
95°C	31	21	0	10	9	1	7	0
110°C	34	20	0	14	13	2	7	0
Requirement[1)]	*30*	-	-	-	*4*	*1*	*5[2)]*	-

1) Indicate the required number of observations according to ISO 9080.

2) Indicate the required number of pressure levels at which at least two observations have been recorded according to paragraph 4.2.1 in ISO 9080.

3) Number of pipes included in the distribution analysis, but not in the regression analysis.

5.3 Regression analysis model

Different analyses were performed adding pipes that still were in progress and using the 3 or 4-parameter models. The 4-parameter model was finally chosen, as the probability level for C_3 was ≤0.05. Table 4 presents the regression coefficients and the standard error values for the selected analysis, i.e. only valid for the pipes with the Exova code 4537.

Table 4 *Regression coefficients for the selected model*

FIRST BRANCH	C_1	C_2	C_3	C_4
Value	-225.110	94 163.473	132.874	-65 749.006
Standard error	16.326	6 674.876	10.512	4 928.273

5.4 Extrapolation time limits

Table 5 below shows the different extrapolation time limits for the different test temperatures.

Table 5 *Extrapolation time limits*

T_t [1]	t_{max} [2]	Extrapolation time limits, t_e [3], at different service temperatures, T_s			
		20°C	**60°C**	**95°C**	**110°C**
20°C	8 918 h	1.02 yrs	-	-	-
60°C	8 785 h	50.1 yrs	1.00 yrs	-	-
95°C	8 804 h	100 yrs [4]	30.2 yrs	1.01 yrs	
110°C	8 763 h	100 yrs [4]	100 yrs [4]	4.00 yrs	1.00 yrs

1) *T_t is the test temperature*

2) *The maximum test time. t_{max} is the logarithmic average of the 5 longest observations.*

3) *The extrapolation time limit, t_e, is calculated from the relation: $t_e = t_{max} \cdot K_e$, where K_e is the extrapolation time factor that is a function of the difference in service temperature T_s and the test temperature, T_t. Underlined values indicate the longest extrapolation time limit obtained at a specific service temperature*

4) *The maximum extrapolation time is 100 yrs*

5.5 Extrapolated strength values

The selected model gives the following extrapolated strength values corresponding to 50 years at 20°C and to the extrapolation time limits at the test temperatures.

Table 6 *Extrapolated strength values*

Time	σ_{LTHS} [MPa]				σ_{LPL} [MPa]			
[h]	**20°C**	**60°C**	**95°C**	**110°C**	**20°C**	**60°C**	**95°C**	**110°C**
10	10.975	7.530	4.455	3.217	10.698	7.268	4.239	3.032
100	10.702	7.266	4.236	3.031	10.437	7.014	4.032	2.859
1 000	10.436	7.011	4.028	2.856	10.178	6.765	3.832	2.692
10 000	10.176	6.765	3.830	-	9.921	6.520	3.638	-
100 000	9.923	6.527	-	-	9.665	6.280	-	-
50 yrs	9.764	6.380	-	-	9.503	6.129	-	-
100 yrs (t_e 20°C)	9.690	-	-	-	9.426	-	-	-
100 yrs (t_e 60°C)	-	6.311	-	-	-	6.059	-	-
4.00 yrs (t_e 95°C)	-	-	3.727	-	-	-	3.536	-
1.00 yrs (t_e 110°C)	-	-	-	2.701	-	-	-	2.542

5.6 Classification according to ISO 12162

By its LPL value of 9.50 MPa at 20°C and 50 years the PE-RT pipe grade SP 988 Natural from LG Chem, Ltd. has a minimum required strength (MRS) of 8 MPa and is thereby designated PE-RT 80 according to ISO 12162:1995.

6 ADDITIONAL COMMENTS

No unusual behaviour was observed during the hydrostatic pressure testing.

REFERRED DOCUMENTS

- ISO 1167:2006
  Thermoplastics pipes, fittings and assemblies for the conveyance of fluids – Determination of the resistance to internal pressure
- ISO 9080:2003
  Plastics piping and ducting systems –Determination of the long-term hydrostatic strength of thermoplastics materials in pipe form by extrapolation
- ISO 12162:2009
  Thermoplastics materials for pipes and fittings for pressure applications — Classification and designation – Overall service (design) coefficient
- ISO 9080 evaluation software
  Pipeson Analyzer® 1.6.6 from Pipeson.
  Pipeson AB, SE-11152 Stockholm, Sweden, Phone: +46 (0)73 415 9798,
  Fax: +46 (0)70 146 2622, E-mail: info@pipeson.se; www.pipeson.se
- ISO 24033:2009
  Polyethylene of raised temperature resistance (PE-RT) pipes – Effect of time and temperature on the expected strength
- ISO 22391:2009
  Plastic piping systems for hot and cold water installations – Polyethylene of raised temperature resistance (PE-RT)

CLIENT INFO

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MATERIAL INFO

Exova code	4537
Trade name	SP988
Material	PE-RT
Colour	Natural
Nominal dimension	16 x 2 mm
Arrival date at Exova	2008-12-17
Amount	249 x 0.35 m
Consignor	LG Chem, Ltd.
Condition of material at arrival	No visual defects
Marking	LG Chem II-SP988X A807077P PE-RT Type 2 sampleNo 08111701 Made by HPG GmbH, Germany Nr.17211171108 Meter xxx
Resin producer	LG Chem, Ltd.
Resin production site	-
Resin production batch no	A807077P
Resin production date	-
Pipe producer	-
Pipe production site	-
Pipe production batch no	-
Pipe production date	-
Method of manufacturing	Extrusion

TEST INFO

Test laboratory	Exova Nyköping Polymer
Responsible	Jimmy Dannérus
Test method	ISO 1167:2006
Length (total/free)	350/310 mm
Fittings	Brass fittings and type A, unless remarked
Internal medium	Water
External medium	Water (Air at 110°C)
Conditioning time	1 h
Situation on	2010-03-05

TABLE REMARKS

Code	Exova internal code
T	Test temperature
Start date	Date when the pipe sample was started
Reg date	Registration date for failure/termination of the pipe sample
e_{min}	Minimum wall thickness
d_{em}	Mean outside diameter
p	Internal pressure
σ	Circumferential stress (hoop stress)
->	The pipe is under test

PIPE REMARKS

1 The sample is excluded from the analysis in accordance with paragraph 4.2.3 in ISO 9080.

2 The sample is fitted with PVDF

The pipe is included in the ISO 9080 evaluaiton

HYDROSTATIC PRESSURE TESTING

Code	T [°C]	Start date [yymmdd]	Reg date [yymmdd]	d_{em} [mm]	e_{min} [mm]	p [bar]	σ [MPa]	Failure time [h]	Failure mode	Test time [h]	Remark
4537-33	20	090119	090119	16.03	2.01	37.27	13.00	2.0	Ductile		
4537-34	20	090119	090120	16.05	2.01	35.80	12.50	4.1	Ductile		
4537-35	20	090119	090120	16.06	2.01	34.32	12.00	8.9	Ductile		
4537-36	20	090119	090120	16.03	2.02	33.34	11.56	22	Ductile		
4537-37	20	090119	090126	16.08	2.01	31.38	10.98	105	Ductile		
4537-61	20	090225	090305	16.08	2.04	31.38	10.80	179	Ductile		
4537-62	20	090225	090317	16.19	2.03	30.40	10.60	479	Ductile		
4537-147	20	090527	090622	16.05	2.03	30.40	10.50	588	Ductile		
4537-108	20	090318	090506	16.03	2.03	30.40	10.48	1 178	Ductile		
4537-109	20	090318	100118	16.06	2.01	29.91	10.46	7 345	Ductile		
4537-148	20	090527	090622	15.99	2.03	30.40	10.45	588	Ductile		
4537-110	20	090318	090522	16.03	2.01	29.91	10.43	1 547	Ductile		
4537-149	20	090527	091012	16.09	2.02	29.91	10.42	3 276	Ductile		
4537-150	20	090527	100122	16.21	2.01	29.42	10.39	5 748	Ductile		
4537-151	20	090527	091005	16.01	2.02	29.91	10.36	3 088	Ductile		
4537-111	20	090318	090615	16.13	2.01	29.42	10.34	2 092	Ductile		
4537-112	20	090318	090819	16.13	2.01	29.42	10.34	3 685	Ductile		
4537-152	20	090527		16.05	2.00	29.42	10.34	->		*>6 758*	
4537-113	20	090318	090901	16.04	2.03	29.91	10.32	4 009	Ductile		
4537-153	20	090527	100129	16.16	2.02	29.42	10.30	5 916	Ductile		
4537-114	20	090318	090813	16.08	2.04	29.91	10.29	3 554	Ductile		
4537-154	20	090527	091126	15.98	2.03	29.91	10.28	4 392	Ductile		
4537-115	20	090318		16.03	2.01	29.42	10.26	->		*>8 438*	
4537-116	20	090318	091019	16.01	2.01	29.42	10.25	5 125	Ductile		
4537-117	20	090318	090819	16.01	2.01	29.42	10.25	3 689	Ductile		
4537-155	20	090527		16.00	2.01	29.42	10.24	->		*>6 758*	
4537-156	20	090527		16.04	2.02	29.42	10.21	->		*>6 758*	
4537-119	20	090318	100203	16.09	2.03	29.42	10.19	7 729	Ductile		
4537-118	20	090318		16.02	2.02	29.42	10.19	->		*>8 438*	
4537-157	20	090527		16.08	2.03	29.42	10.18	->		*>6 758*	
4537-120	20	090318		16.05	2.03	29.42	10.16	->		*>8 438*	
4537-158	20	090527		15.94	1.99	28.93	10.14	->		*>6 758*	

HYDROSTATIC PRESSURE TESTING

Code	T	Start date	Reg date	d_{em}	e_{min}	p	σ	Failure time	Failure mode	Test time	Remark
	[°C]	[yymmdd]	[yymmdd]	[mm]	[mm]	[bar]	[MPa]	[h]		[h]	
4537-121	20	090318		16.06	1.97	28.34	10.14	->		*>8 438*	
4537-63	20	090225		16.12	2.02	28.93	10.10	->		*>8 942*	
4537-122	20	090318		16.13	2.02	28.93	10.10	->		*>8 438*	
4537-64	20	090225	100123	16.00	2.01	28.93	10.07	-	Stopped	*7 968*	
4537-65	20	090225	100123	16.12	2.03	28.93	10.04	-	Stopped	*7 968*	
4537-1	20	081222		16.15	2.04	28.93	10.01	->		*>10 502*	
4537-66	20	090225	100123	16.07	2.03	28.93	10.00	-	Stopped	*7 968*	
4537-67	20	090225	100123	16.05	2.03	28.93	9.99	-	Stopped	*7 968*	
4537-68	20	090225	100123	16.01	2.03	28.93	9.96	-	Stopped	*7 968*	
4537-69	20	090225	100123	15.96	2.03	28.93	9.93	-	Stopped	*7 968*	
4537-70	20	090225	100123	16.05	2.01	28.34	9.90	-	Stopped	*7 968*	
4537-2	20	081222	100123	16.07	2.05	28.93	9.89	-	Stopped	*9 528*	
4537-71	20	090225	100123	16.06	2.02	28.34	9.85	-	Stopped	*7 968*	
4537-72	20	090225	100123	16.09	2.02	27.85	9.70	-	Stopped	*7 968*	
4537-3	20	081222	100123	16.19	2.05	27.85	9.60	-	Stopped	*9 528*	
4537-4	20	081222	100123	16.06	2.04	27.36	9.40	-	Stopped	*9 528*	
4537-5	20	081222	100123	16.06	2.04	27.07	9.30	-	Stopped	*9 528*	
4537-6	20	081222	100123	16.04	2.03	26.09	9.00	-	Stopped	*9 528*	

HYDROSTATIC PRESSURE TESTING

Code	T [°C]	Start date [yymmdd]	Reg date [yymmdd]	d_{em} [mm]	e_{min} [mm]	p [bar]	σ [MPa]	Failure time [h]	Failure mode	Test time [h]	Remark
4537-38	60	090119	090119	16.08	2.01	22.26	7.79	0.6	Ductile		
4537-39	60	090119	090120	16.09	2.00	21.58	7.60	1.7	Ductile		
4537-184	60	091001	091001	16.05	2.01	21.38	7.47	5.0	Ductile		
4537-185	60	091001	091001	16.04	2.02	21.38	7.42	5.0	Ductile		
4537-40	60	090119	090120	16.05	2.01	21.18	7.40	4.7	Ductile		
4537-186	60	091001	091002	16.05	2.02	21.18	7.36	5.0	Ductile		
4537-187	60	091001	091002	16.02	2.03	21.18	7.30	5.0	Ductile		
4537-169	60	090803	090805	16.11	2.01	20.79	7.29	37	Ductile		
4537-170	60	090803	090804	16.07	2.04	21.18	7.28	4.0	Ductile		
4537-171	60	090803	090804	15.97	2.03	21.18	7.27	8.1	Ductile		
4537-172	60	090803	090805	16.04	2.01	20.79	7.26	29	Ductile		
4537-41	60	090119	090122	16.03	2.01	20.79	7.25	62	Ductile		
4537-173	60	090803	090806	16.01	2.01	20.79	7.24	52	Ductile		
4537-175	60	090803	090806	16.03	2.02	20.79	7.21	54	Ductile		
4537-188	60	091001	091005	16.04	2.02	20.79	7.21	29	Ductile		
4537-174	60	090803	090810	16.08	2.00	20.50	7.21	114	Ductile		
4537-176	60	090803	090806	16.07	2.03	20.79	7.19	73	Ductile		
4537-178	60	090803	090806	15.98	2.02	20.79	7.18	61	Ductile		
4537-177	60	090803	090810	16.02	2.00	20.50	7.18	156	Ductile		
4537-189	60	091001	091005	15.98	2.03	20.79	7.14	68	Ductile		
4537-42	60	090119	090126	16.03	2.02	20.50	7.11	164	Ductile		
4537-179	60	090803	090811	16.03	2.02	20.50	7.11	181	Ductile		
4537-180	60	090803	090811	16.03	2.02	20.50	7.11	193	Ductile		
4537-181	60	090803	090811	16.02	2.02	20.50	7.10	184	Ductile		
4537-190	60	091001	091008	16.07	2.03	20.50	7.09	166	Ductile		
4537-182	60	090803	090817	16.06	2.03	20.50	7.08	337	Ductile		
4537-183	60	090803	090817	16.14	2.01	20.10	7.07	301	Ductile		
4537-43	60	090119	091103	16.09	2.02	20.10	7.00	6 911	Ductile		
4537-159	60	090527	091012	16.14	2.01	19.91	7.00	3 276	Ductile		
4537-191	60	091001		15.99	2.01	20.10	6.99	->		*>3 710*	
4537-160	60	090527	091005	16.02	2.02	20.10	6.97	3 120	Ductile		
4537-44	60	090119	090716	16.03	2.02	19.91	6.90	4 259	Ductile		

HYDROSTATIC PRESSURE TESTING

Code	T	Start date	Reg date	d_{em}	e_{min}	p	σ	Failure time	Failure mode	Test time	Remark
	[°C]	[yymmdd]	[yymmdd]	[mm]	[mm]	[bar]	[MPa]	[h]		[h]	
4537-161	60	090527		15.99	2.02	19.91	6.88	->		*>6 758*	
4537-162	60	090527		15.99	2.03	19.91	6.85	->		*>6 758*	
4537-163	60	090527		16.08	2.01	19.42	6.80	->		*>6 758*	
4537-164	60	090527	100123	16.06	2.02	19.42	6.75	-	Stopped	*5 784*	
4537-165	60	090527	100123	16.03	2.02	19.42	6.73	-	Stopped	*5 784*	
4537-166	60	090527	100123	16.02	2.02	19.42	6.73	-	Stopped	*5 784*	
4537-167	60	090527	100123	16.03	2.02	19.42	6.73	-	Stopped	*5 784*	
4537-73	60	090224		16.24	2.02	19.03	6.70	->		*>8 966*	
4537-168	60	090527	100123	16.02	2.03	19.42	6.69	-	Stopped	*5 784*	
4537-74	60	090224		16.08	2.04	19.42	6.68	->		*>8 966*	
4537-75	60	090224		15.98	2.03	19.42	6.67	->		*>8 966*	
4537-76	60	090224	100123	16.03	2.04	19.42	6.66	-	Stopped	*7 992*	
4537-77	60	090224	100123	16.09	2.05	19.42	6.65	-	Stopped	*7 992*	
4537-78	60	090224	100123	16.12	2.02	19.03	6.64	-	Stopped	*7 992*	
4537-79	60	090224	100123	16.06	2.02	19.03	6.61	-	Stopped	*7 992*	
4537-80	60	090224	100123	16.06	2.02	19.03	6.61	-	Stopped	*7 992*	
4537-81	60	090224	100123	16.14	2.03	19.03	6.61	-	Stopped	*7 992*	
4537-7	60	081222		16.11	2.03	19.03	6.60	->		*>10 502*	
4537-82	60	090224	100123	16.10	2.03	19.03	6.59	-	Stopped	*7 992*	
4537-8	60	081222	100123	16.09	2.04	19.03	6.55	-	Stopped	*9 528*	
4537-9	60	081222	100123	16.06	2.05	19.03	6.50	-	Stopped	*9 528*	
4537-10	60	081222	100123	16.05	2.04	18.63	6.40	-	Stopped	*9 528*	
4537-11	60	081222	100123	16.04	2.05	18.63	6.36	-	Stopped	*9 528*	
4537-12	60	081222	100123	16.10	2.06	18.63	6.35	-	Stopped	*9 528*	
4537-13	60	081222	100123	16.05	2.03	18.24	6.30	-	Stopped	*9 528*	
4537-14	60	081222	100123	16.07	2.04	18.04	6.20	-	Stopped	*9 528*	

HYDROSTATIC PRESSURE TESTING

Code	T [°C]	Start date [yymmdd]	Reg date [yymmdd]	d_{em} [mm]	e_{min} [mm]	p [bar]	σ [MPa]	Failure time [h]	Failure mode	Test time [h]	Remark
4537-45	95	090119	090120	16.06	2.01	12.85	4.49	1.0	Ductile		
4537-46	95	090119	090121	16.07	2.02	12.36	4.30	43	Ductile		
4537-123	95	090525	090526	16.14	2.03	12.36	4.29	7.1	Ductile		
4537-124	95	090525	090526	16.05	2.02	12.36	4.29	21	Ductile		
4537-125	95	090525	090529	16.10	2.03	12.36	4.28	82	Ductile		
4537-126	95	090525	090527	16.04	2.04	12.36	4.24	36	Ductile		
4537-47	95	090119	090128	16.05	2.00	12.06	4.24	199	Ductile		
4537-127	95	090525	090528	16.07	2.05	12.36	4.23	53	Ductile		
4537-128	95	090525	090528	16.07	2.05	12.36	4.23	60	Ductile		
4537-192	95	091001	091013	16.07	2.02	12.06	4.20	280	Ductile		
4537-129	95	090525	090604	16.06	2.02	12.06	4.19	221	Ductile		
4537-193	95	091001	091026	16.05	2.02	12.06	4.19	591	Ductile		
4537-194	95	091001	091005	16.03	2.02	12.06	4.18	73	Ductile		
4537-130	95	090525	090906	16.08	2.03	12.06	4.17	2 476	Ductile		
4537-48	95	090119	090309	16.06	2.00	11.87	4.17	1 144	Ductile		
4537-195	95	091001	091124	16.04	2.03	12.06	4.16	1 285	Ductile		
4537-131	95	090525	090602	16.07	2.04	12.06	4.15	190	Ductile		
4537-196	95	091001	091019	15.99	2.03	12.06	4.15	397	Ductile		
4537-132	95	090525	090612	16.03	2.04	12.06	4.14	418	Ductile		
4537-197	95	091001	091117	16.04	2.01	11.87	4.14	1 129	Ductile		
4537-198	95	091001	100123	15.97	2.01	11.87	4.12	-	Stopped	*2 736*	
4537-133	95	090525	090921	16.08	2.01	11.77	4.12	2 854	Ductile		
4537-199	95	091001	100125	15.97	2.02	11.87	4.10	-	Stopped	*2 736*	
4537-134	95	090525	090720	16.09	2.02	11.77	4.10	1 306	Ductile		
4537-49	95	090119	090608	16.07	2.02	11.77	4.09	3 330	Ductile		
4537-200	95	091001	100123	15.99	2.03	11.77	4.05	-	Stopped	*2 736*	
4537-50	95	090119	100123	16.04	2.02	11.57	4.02	-	Stopped	*8 856*	
4537-83	95	090224	100123	16.07	2.03	11.57	4.00	-	Stopped	*7 992*	
4537-84	95	090224	100123	16.16	2.02	11.38	3.98	-	Stopped	*7 992*	
4537-51	95	090119	100123	16.05	2.02	11.38	3.95	-	Stopped	*8 856*	
4537-85	95	090224	100123	16.13	2.03	11.38	3.95	-	Stopped	*7 992*	
4537-86	95	090224	100123	16.07	2.03	11.38	3.93	-	Stopped	*7 992*	

HYDROSTATIC PRESSURE TESTING

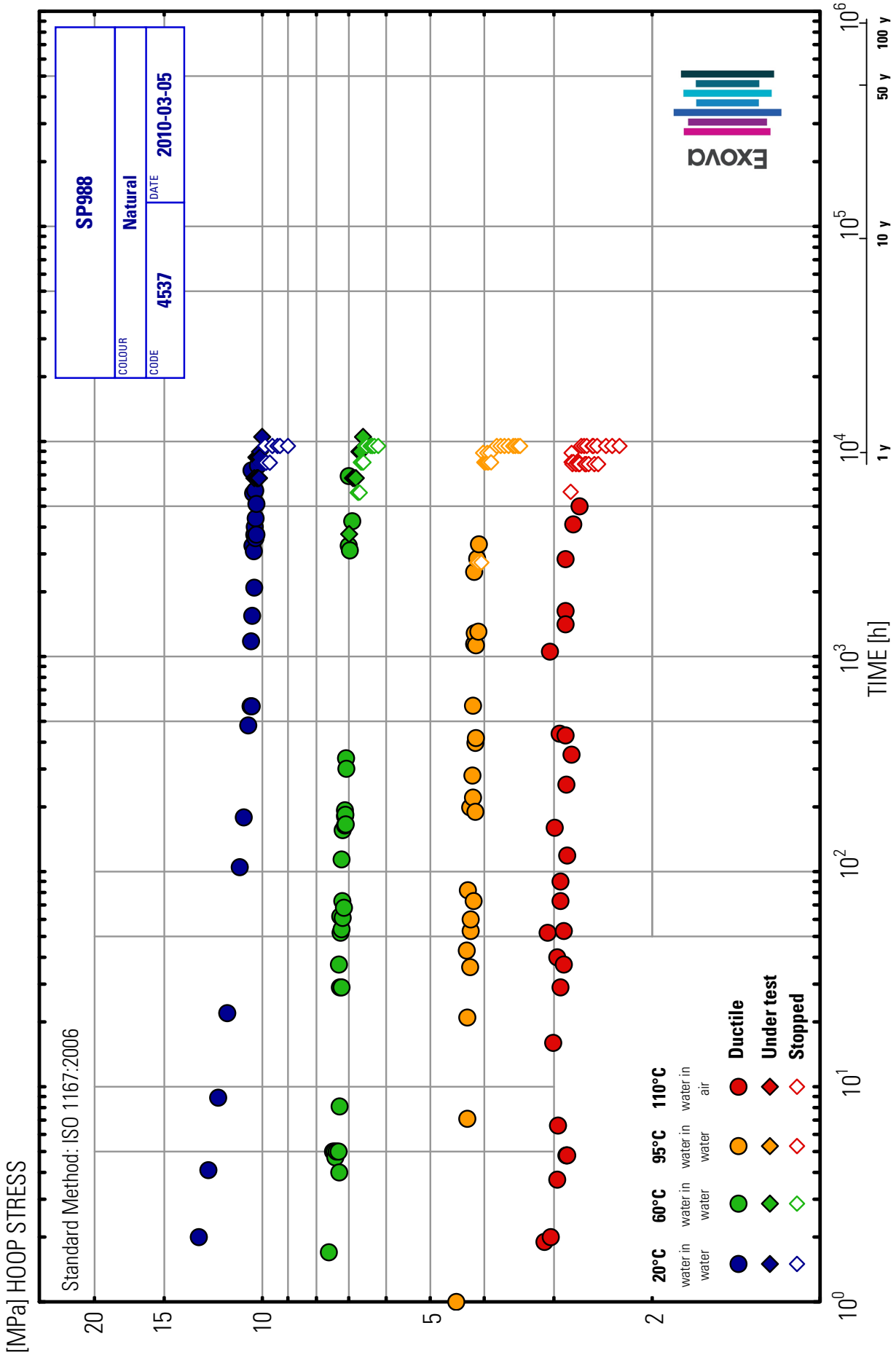
Code	T [°C]	Start date [yymmdd]	Reg date [yymmdd]	d_{em} [mm]	e_{min} [mm]	p [bar]	σ [MPa]	Failure time [h]	Failure mode	Test time [h]	Remark
4537-52	95	090119	100123	16.04	2.01	11.18	3.90	-	Stopped	*8 856*	
4537-87	95	090224	100123	16.06	2.02	11.18	3.89	-	Stopped	*7 992*	
4537-15	95	081222	100123	16.09	2.03	10.98	3.80	-	Stopped	*9 528*	
4537-16	95	081222	100123	16.25	2.05	10.79	3.74	-	Stopped	*9 528*	
4537-17	95	081222	100123	16.02	2.05	10.79	3.68	-	Stopped	*9 528*	
4537-18	95	081222	100123	16.05	2.05	10.59	3.62	-	Stopped	*9 528*	
4537-19	95	081222	100123	16.12	2.04	10.30	3.55	-	Stopped	*9 528*	
4537-20	95	081222	100123	15.99	2.04	10.30	3.52	-	Stopped	*9 528*	
4537-21	95	081222	100123	16.08	2.04	10.10	3.48	-	Stopped	*9 528*	
4537-22	95	081222	100123	16.05	2.05	10.10	3.45	-	Stopped	*9 528*	

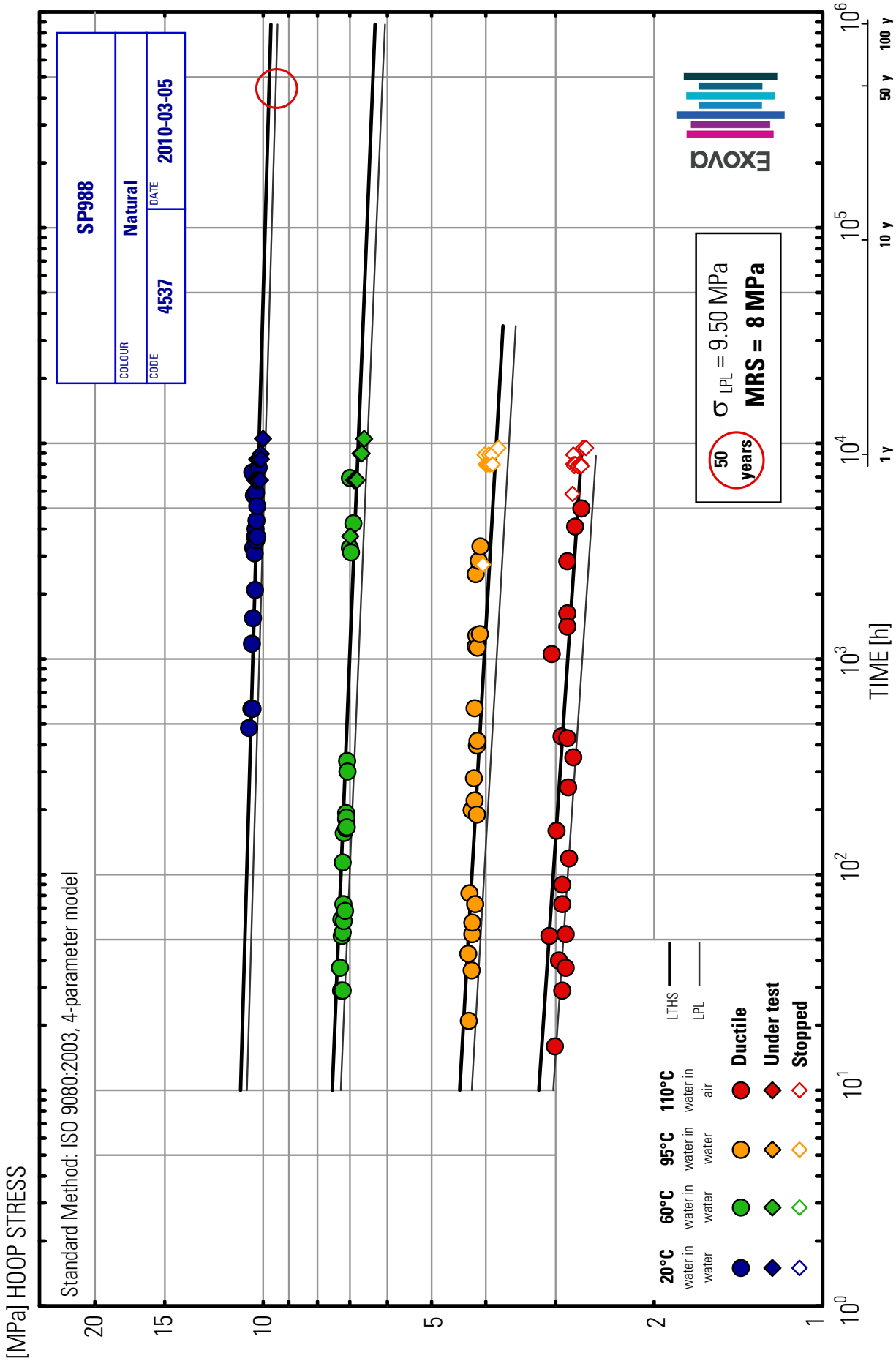
HYDROSTATIC PRESSURE TESTING

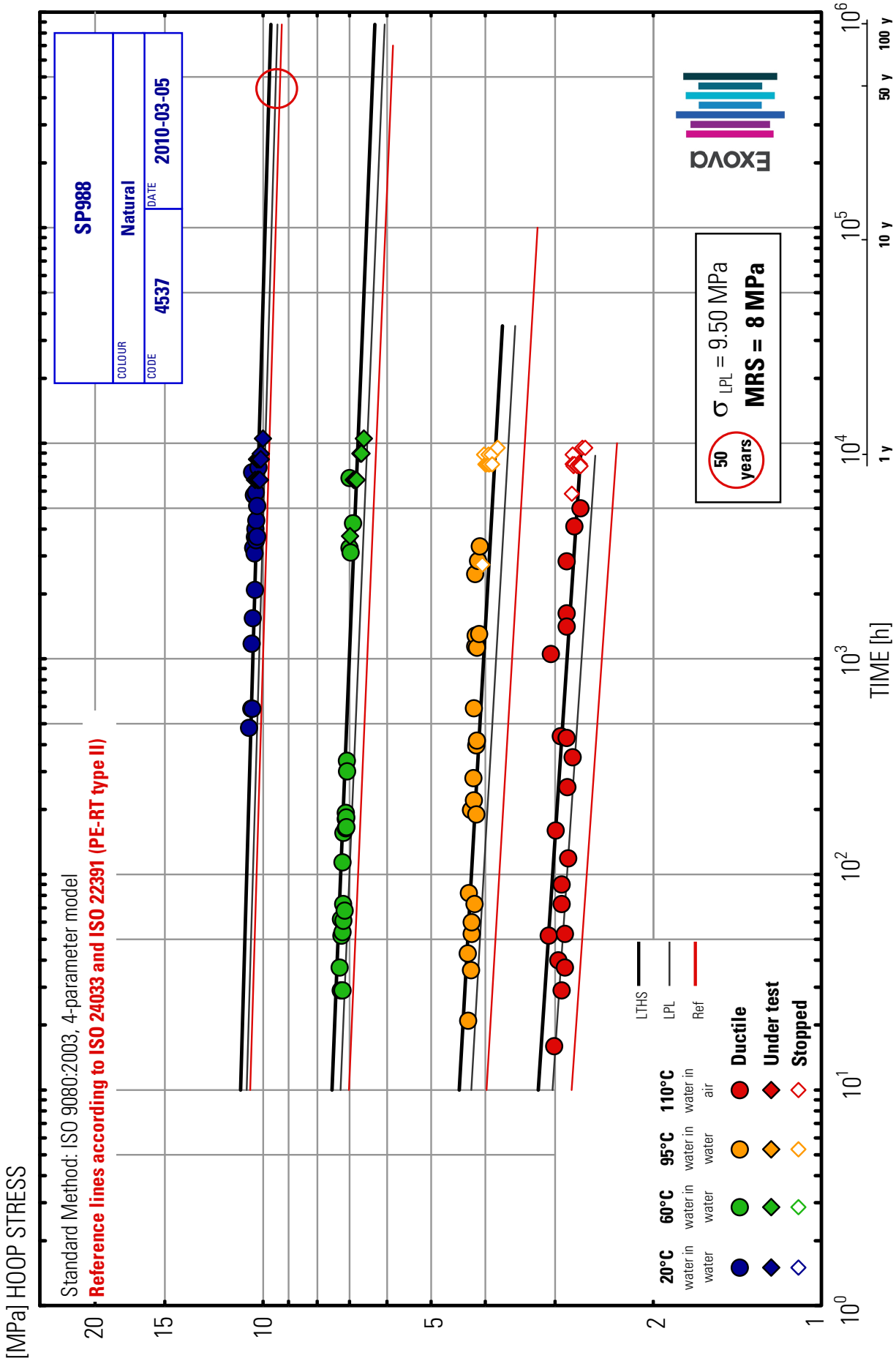
Code	T [°C]	Start date [yymmdd]	Reg date [yymmdd]	d_{em} [mm]	e_{min} [mm]	p [bar]	σ [MPa]	Failure time [h]	Failure mode	Test time [h]	Remark
4537-135	110	090525	090525	16.14	2.04	9.02	3.12	1.9	Ductile		
4537-53	110	090119	090122	16.05	2.01	8.83	3.08	52	Ductile		
4537-136	110	090525	090708	16.06	2.03	8.83	3.05	1 055	Ductile		
4537-137	110	090525	090525	16.11	2.04	8.83	3.04	2.0	Ductile		
4537-54	110	090119	090120	16.04	2.01	8.63	3.01	16	Ductile		
4537-138	110	090525	090601	16.08	2.03	8.63	2.99	160	Ductile		
4537-55	110	090119	090121	16.04	2.02	8.53	2.96	40	Ductile		
4537-139	110	090525	090525	16.14	2.03	8.53	2.96	3.7	Ductile		
4537-140	110	090525	090525	16.06	2.03	8.53	2.95	6.6	Ductile		
4537-141	110	090525	090615	16.06	2.04	8.53	2.93	438	Ductile		
4537-142	110	090525	090529	16.08	2.05	8.53	2.92	90	Ductile		*1*
4537-203	110	091001	091005	15.98	2.04	8.53	2.92	29	Ductile		
4537-201	110	091001	091005	16.11	1.99	8.24	2.92	73	Ductile		
4537-56	110	090119	090122	16.04	2.01	8.24	2.88	53	Ductile		
4537-202	110	091001	091005	16.00	2.00	8.24	2.88	37	Ductile		
4537-57	110	090119	090518	16.05	2.02	8.24	2.86	2 841	Ductile		
4537-58	110	090119	090330	16.05	2.02	8.24	2.86	1 629	Ductile		
4537-59	110	090119	090319	16.04	2.02	8.24	2.86	1 413	Ductile		
4537-143	110	090525	090612	16.10	2.03	8.24	2.86	430	Ductile		*1*
4537-88	110	090223	090306	16.09	2.03	8.24	2.85	254	Ductile		
4537-144	110	090525	090525	16.07	2.03	8.24	2.85	4.8	Ductile		*1*
4537-89	110	090223	090302	16.12	2.04	8.24	2.84	119	Ductile		
4537-145	110	090525	090525	16.03	2.03	8.24	2.84	4.8	Ductile		*1*
4537-146	110	090525	100123	16.07	2.02	8.04	2.80	-	Stopped	*5 832*	*1*
4537-90	110	090223	090310	16.13	2.03	8.04	2.79	350	Ductile		
4537-60	110	090119	100129	16.04	2.02	8.04	2.79	-	Stopped	*8 856*	
4537-91	110	090223	100123	16.10	2.03	8.04	2.79	-	Stopped	*8 016*	
4537-98	110	090302	100123	16.05	2.03	8.04	2.78	-	Stopped	*7 848*	*1*
4537-97	110	090223	090814	16.04	2.03	8.04	2.77	4 118	Ductile		*1*
4537-92	110	090223	100123	16.12	2.04	8.04	2.77	-	Stopped	*8 016*	
4537-99	110	090302	100123	16.07	2.01	7.85	2.74	-	Stopped	*7 848*	*1*
4537-93	110	090223	100123	16.02	2.02	7.85	2.72	-	Stopped	*8 016*	

HYDROSTATIC PRESSURE TESTING

Code	T [°C]	Start date [yymmdd]	Reg date [yymmdd]	d_{em} [mm]	e_{min} [mm]	p [bar]	σ [MPa]	Failure time [h]	Failure mode	Test time [h]	Remark
4537-94	110	090223	100129	16.09	2.03	7.85	2.72	-	Stopped	*8 016*	
4537-95	110	090223	100123	16.01	2.02	7.85	2.72	-	Stopped	*8 016*	
4537-96	110	090223	100123	16.04	2.03	7.85	2.71	-	Stopped	*8 016*	*1*
4537-100	110	090302	100123	16.17	2.00	7.65	2.71	-	Stopped	*7 848*	*1*
4537-23	110	081222	090720	16.07	2.04	7.85	2.70	4 996	Ductile		
4537-101	110	090302	100123	16.13	2.00	7.65	2.70	-	Stopped	*7 848*	*1*
4537-24	110	081222	100123	15.98	2.04	7.85	2.68	-	Stopped	*9 528*	
4537-25	110	081222	100123	16.11	2.03	7.65	2.65	-	Stopped	*9 528*	
4537-102	110	090302	100123	16.10	1.99	7.45	2.64	-	Stopped	*7 848*	*1*
4537-103	110	090302	100123	16.19	2.01	7.45	2.63	-	Stopped	*7 848*	*1*
4537-104	110	090302	100123	16.11	2.00	7.45	2.63	-	Stopped	*7 848*	*1*
4537-26	110	081222	100123	16.10	2.05	7.65	2.62	-	Stopped	*9 528*	
4537-105	110	090302	100123	16.12	2.02	7.45	2.60	-	Stopped	*7 848*	*1*
4537-27	110	081222	100123	16.04	2.04	7.45	2.56	-	Stopped	*9 528*	
4537-28	110	081222	100123	16.07	2.05	7.45	2.55	-	Stopped	*9 528*	
4537-106	110	090302	100123	16.07	2.03	7.36	2.54	-	Stopped	*7 848*	*1*
4537-29	110	081222	100123	16.06	2.05	7.36	2.51	-	Stopped	*9 528*	
4537-107	110	090302	100123	16.05	2.01	7.16	2.50	-	Stopped	*7 848*	*1*
4537-30	110	081222	100123	16.11	2.05	7.06	2.42	-	Stopped	*9 528*	
4537-31	110	081222	100123	16.12	2.05	6.86	2.36	-	Stopped	*9 528*	
4537-32	110	081222	100123	16.11	2.05	6.67	2.29	-	Stopped	*9 528*	


SP988
Natural
2010-03-05
DATE
COLOUR
CODE
4537
EXOVA
[MPa] HOOP STRESS
Standard Method: ISO 1167:2006
TIME [h]
20
15
10
5
2
10^0
10^1
10^2
10^3
10^4
10^5
10^6
1 y
10 y
50 y
100 y
20°C water in water
60°C water in water
95°C water in water
110°C water in air
Ductile
Under test
Stopped


SP988
Natural
COLOUR
CODE
4537
DATE
2010-03-05
EXOVA
σ LPL = 9.50 MPa
MRS = 8 MPa
50 years
[MPa] HOOP STRESS
Standard Method: ISO 9080:2003, 4-parameter model
TIME [h]
20°C water in water
60°C water in water
95°C water in water
110°C water in air
Ductile
Under test
Stopped
LTHS
LPL
1 y
10 y
50 y
100 y


SP988
Natural
2010-03-05
4537
COLOUR
CODE
DATE
EXOVA
σ LPL = 9.50 MPa
MRS = 8 MPa
50 years
[MPa] HOOP STRESS
Standard Method: ISO 9080:2003, 4-parameter model
Reference lines according to ISO 24033 and ISO 22391 (PE-RT type II)
TIME [h]
1 y
10 y
50 y
100 y
20°C water in water
60°C water in water
95°C water in water
110°C water in air
Ductile
Under test
Stopped
LTHS
LPL
Ref

EXOVA/P-10/40

DETERMINATION OF THE LONG-TERM HYDROSTATIC STRENGTH
ISO 9080:2003-evaluation of the PE-RT pipe grade SP 988 Natural from LG Chem, Ltd.

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