BODYCOTE/P-09/53

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BODYCOTE REPORT

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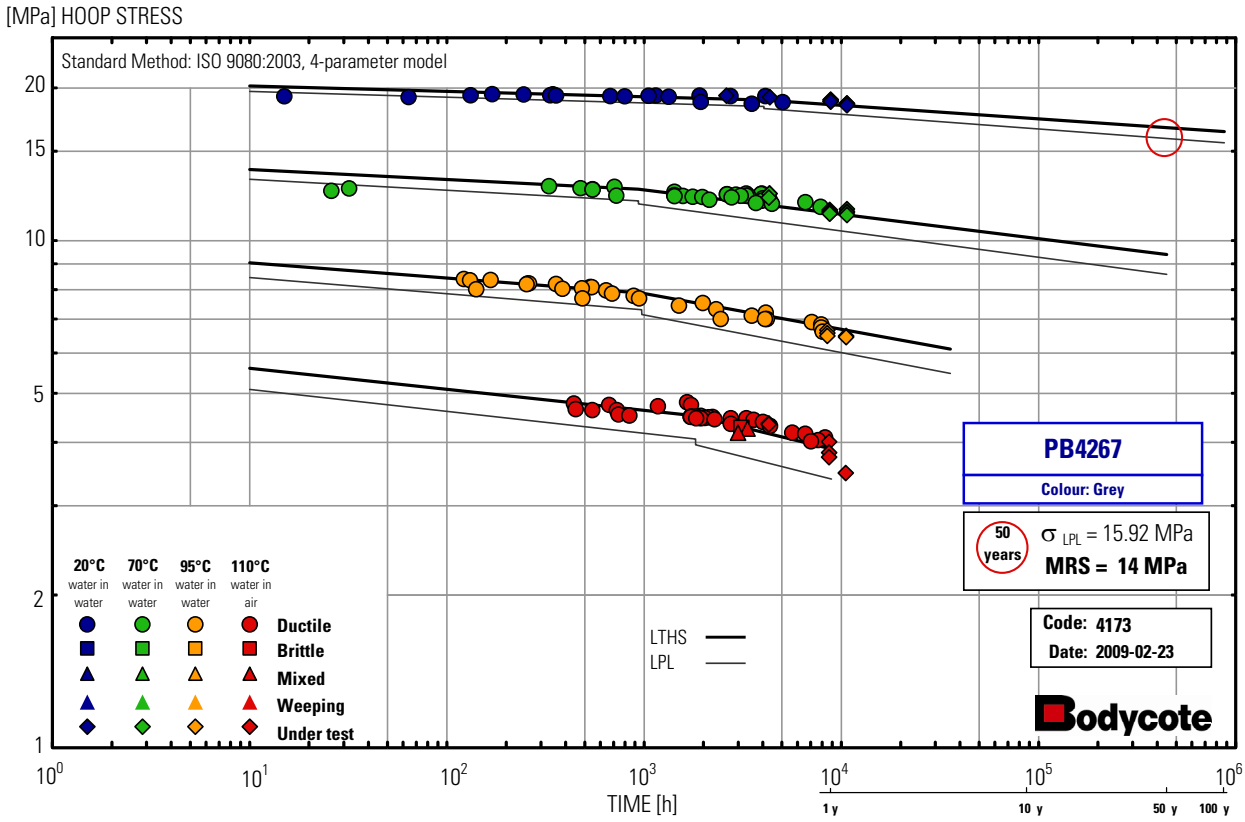
DETERMINATION OF THE LONG-TERM HYDROSTATIC STRENGTH

ISO 9080:2003-evaluation of the PB pipe compound PB4267 Grey from LYONDELLBASELL INDUSTRIES

Mattias SVEDBERG



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DETERMINATION OF THE LONG-TERM HYDROSTATIC STRENGTH ISO 9080:2003-evaluation of the PB pipe compound PB4267 Grey from LYONDELLBASELL INDUSTRIES

ABSTRACT

The aim of this project was to determine the long term hydrostatic strength of the PB pipe compound PB4267 Grey according to ISO 9080 and then MRS-classify it according to ISO 12162.

The ISO 9080-evaluation of the material gives the following strength values at 20 and 70°C;

T	Time	σ_{LPL}	σ_{LTHS}
20°C	50 yrs	15.92 MPa	16.71 MPa
70°C	50 yrs	8.59 MPa	9.40 MPa

By its LPL value of 15.92 MPa at 20°C and 50 years the PB pipe compound PB4267 Grey has a minimum required strength (MRS) of 14 MPa and is thereby designated PB 140 according to ISO 12162:1995.

LIST OF CONTENTS

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1 EVALUATED PIPE COMPOUND

A short presentation of the evaluated material is presented below. Detailed information about the material is given in Appendix B.

Table 1 *Evaluated pipe compound*

Trade name	PB4267
Pipe colour	Grey
Pipe material	PB
Nominal pipe dimension	20 x 1.9 mm
Bodycote internal code	4173

2 EXPERIMENTAL PROCEDURE

The hydrostatic pressure testing is performed at Bodycote according to ISO 1167:2006. The pressure testing at 20, 70 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	43	22	21	0	5 047	10 680
70°C	51	33	18	0	7 861	10 680
95°C	41	30	11	0	8 040	10 584
110°C	60	43	17	2	8 610	10 536

[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-4/02 and is documented at Bodycote.

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 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	31	19	12	0	10	5	6	0
70°C	44	32	12	0	10	4	9	0
95°C	34	29	5	0	9	2	11	0
110°C	41	35	6	0	7	1	10	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.

5.2 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 for both branches, as the probability level for C3 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 Bodycote code 4128.

Table 4 *Regression coefficients for the selected model*

FIRST BRANCH	**C_1**	**C_2**	**C_3**	**C_4**
Value	-321.825	130 615.621	203.517	-87 234.932
Standard error	64.929	25 984.056	41.801	17 662.387
SECOND BRANCH	**C_1**	**C_2**	**C_3**	**C_4**
Value	-124.684	51 670.700	77.378	-33 694.242
Standard error	12.307	4 923.382	7.8	3 317.728

Table 4 a *Knee positions*

T	Hoop stress	Time
20°C	18.93 MPa	4 052.1 h
70°C	12.63 MPa	935.7 h
95°C	7.88 MPa	972.9 h
110°C	4.51 MPa	1 825.7 h

5.3 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	70°C	95°C	110°C
20°C	10 680 h	1.22 yrs	-	-	-
70°C	10 259 h	100 yrs	1.17 yrs	-	-
95°C	9 277 h	100 yrs	12.7 yrs	1.06 yrs	-
110°C	8 927 h	100 yrs [4]	50.9 yrs	4.08 yrs	1.02 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*

5.4 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**	**70°C**	**95°C**	**110°C**	**20°C**	**70°C**	**95°C**	**110°C**
10	20.176	13.812	9.035	5.598	19.683	13.213	8.457	5.092
100	19.688	13.198	8.434	5.089	19.246	12.622	7.901	4.651
1 000	19.212	12.589	7.864	4.627	18.745	11.782	7.135	4.188
10 000	18.478	11.270	6.682		17.764	10.504	6.030	
100 000	17.380	10.090			16.635	9.309		
50 yrs	16.709	9.399			15.923	8.593		
100 yrs (t_e 20°C)	16.404				15.593			
50.9 yrs (t_e 70°C)		9.390				8.584		
4.08 yrs (t_e 95°C)			6.107				5.473	
1.02 yrs (t_e 110°C)				3.883				3.387

5.5 Classification according to ISO 12162

By its LPL value of 15.92 MPa at 20°C and 50 years the PB pipe compound PB4267 Grey has a minimum required strength (MRS) of 14 MPa and is thereby designated PB 140 according to ISO 12162:1995.

6 CALCULATIONS OF DESIGN HOOP STRESS

Miner´s rule calculations have been performed according to ISO 13760:1998 for application classes Class 1, 2, 4 and 5 in order to determine the design hoop stress. Table 8 shows the classification of service conditions according for the different application classes according to ISO 10508:2006.

Table 8 *Classification of service conditions according to ISO 10508*

Class	T_0		T_{max}		T_{mal}		Example of application
	T [°C]	time [yrs]	T [°C]	time [yrs]	T [°C]	time [h]	
1	60	49	80	1	95	100	Hot water supply (60°C)
2	70	49	80	1	95	100	Hot water supply (70°C)
4	20[1)]	2.5	70	2.5	100	100	Under-floor heating and low-temperature radiators
	40	20					
	60	25					
5	20[1)]	14	90	1	100	100	High-temperature radiators
	60	25					
	80	10					

The design hoop stresses for the application classes for the pipe compound PB4267 Grey are presented in Table 9 below.

Table 9 *Resulting design hoop stresses*

Application class	Design hoop stresses [MPa]	
	PB4267 Grey	ISO 15876-2
1	7.11	5.73
2	6.25	5.04
4	7.42	5.46
5	5.50	4.31

The calculated Class 1, 2, 4 and 5 design stresses for the pipe compound PB4267 Grey meet the requirements in ISO 15876.

7 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 12162:1995
  Thermoplastics materials for pipes and fittings for pressure applications — Classification and designation – Overall service (design) coefficient
- ISO 9080 evaluation software
  Pipeson Analyzer® 1.5.4 from Pipeson. More info at www.pipeson.se
- ISO 15876:2003
  Plastics piping systems for hot and cold water installations - Polybutylene (PB)
- ISO 10508:2006
  Plastic piping systems for hot and cold water – Guidance for classification and design
- ISO 13760:1998
  Plastics pipes for the conveyance of fluids under pressure – Miner's rule – Calculation method for cumulative damage

2009-03-04

CLIENT INFO

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2009-03-04

MATERIAL INFO

Bodycote code	4173
Trade name	PB4267
Material	PB
Colour	Grey
Nominal dimension	20 x 1.9 mm
Arrival date at Bodycote	2007-11-27
Amount	250 x 1.2 m
Consignor	LyondellBasell Indusrties
Condition of material at arrival	No visual defects
Marking	na
Resin producer (date, batch no.)	LyondellBasell Indusrties
Pipe producer (date, lot no.)	LyondellBasell Indusrties
Method of manufacturing	Extrusion

TEST INFO

Test laboratory	Bodycote
Responsible	Jimmy Dannérus
Test method	ISO 1167:2006
Length (total/free)	350/310 mm
Fittings	Brass and PVDF fittings, type A
Internal medium	Water
External medium	Water (Air at 110 °C)
Conditioning time	1 h (16 h at 110 °C)
Situation on	2009-02-23

TABLE REMARKS

Code	Bodycote internal code
T	Test temperature
Start date	Date when the pipe sample was started
Reg date	Registration date for failure/termination of the pipe specimen
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 failure occurred closer than 0.1 x L0 from an end cap, where L0 is the free length of the pipe, and may therefore be discarded according to ISO 1167-2 clause 10.4

2 The samples is fitted with PVDF

3 The failure is considered as a degradative so called Stage III failure and should be discarded from the evaluation according to paragraph 5.1.2 in ISO 9080

4 The sample failed due to a technical error on 2008-09-10

The pipe is included in the ISO 9080 evaluaiton

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]	
4173-1	20	071206	071207	20.10	2.15	46.68	19.49	0.2	Ductile		
4173-48	20	080221	080317	20.12	2.12	45.80	19.44	170	Ductile		
4173-49	20	080221	080307	20.11	2.12	45.80	19.43	345	Ductile		
4173-50	20	080221	080303	20.09	2.12	45.80	19.41	245	Ductile		
4173-51	20	080221	080307	20.12	2.13	45.80	19.34	335	Ductile		
4173-191	20	081120	081126	20.10	2.10	45.11	19.33	132	Ductile		
4173-52	20	080221	080307	20.10	2.13	45.80	19.32	358	Ductile		
4173-192	20	081106	081226	20.08	2.14	46.09	19.32	1 146	Ductile		
4173-193	20	081106		20.08	2.14	46.09	19.32	->		*>2 616*	
4173-194	20	081104	090123	20.11	2.12	45.50	19.31	1 913	Ductile		
4173-139	20	080826	081009	20.10	2.12	45.50	19.30	1 055	Ductile		
4173-140	20	080826	080826	20.09	2.12	45.50	19.28	2.1	Ductile		
4173-141	20	080826	080923	20.08	2.12	45.50	19.27	674	Ductile		
4173-142	20	080826	090216	20.07	2.12	45.50	19.27	4 129	Ductile		
4173-144	20	080826	081219	20.14	2.14	45.80	19.26	2 750	Ductile		
4173-143	20	080826	080929	20.06	2.12	45.50	19.25	799	Ductile		
4173-195	20	081120	081121	20.11	2.11	45.11	19.24	15	Ductile		
4173-145	20	080826	081021	20.10	2.14	45.80	19.22	1 336	Ductile		
4173-146	20	080826	080826	20.08	2.14	45.80	19.20	5.0	Ductile		
4173-147	20	080826		20.06	2.14	45.80	19.18	->		*>4 344*	
4173-148	20	080826	080829	20.06	2.14	45.80	19.18	64	Ductile		
4173-53	20	080221		20.11	2.11	44.43	18.95	->		*>8 832*	
4173-54	20	080221		20.11	2.11	44.43	18.95	->		*>8 832*	
4173-55	20	080221		20.10	2.11	44.13	18.81	->		*>8 832*	
4173-56	20	080221		20.10	2.11	44.13	18.81	->		*>8 832*	
4173-57	20	080221		20.10	2.11	44.13	18.81	->		*>8 832*	
4173-2	20	071206	080225	20.14	2.12	44.13	18.76	1 938	Ductile		
4173-3	20	071206	080704	20.13	2.12	44.13	18.75	5 047	Ductile		
4173-4	20	071206		20.13	2.13	44.13	18.65	->		*>10 680*	
4173-5	20	071206		20.11	2.13	44.13	18.63	->		*>10 680*	
4173-6	20	071206	080502	20.10	2.13	44.13	18.62	3 522	Ductile		
4173-7	20	071206		20.13	2.14	44.13	18.55	->		*>10 680*	

2009-03-04

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]	
4173-8	20	071206		20.12	2.14	44.13	18.54	->		*>10 680*	
4173-9	20	071206		20.07	2.14	44.13	18.49	->		*>10 680*	
4173-111	20	080325		20.12	2.13	42.86	18.10	->		*>8 040*	
4173-10	20	071206		20.12	2.14	42.86	18.00	->		*>10 680*	
4173-112	20	080325		20.13	2.11	41.48	17.72	->		*>8 040*	
4173-113	20	080325		20.14	2.12	40.60	17.26	->		*>8 040*	
4173-114	20	080325		20.14	2.12	39.91	16.96	->		*>8 040*	
4173-115	20	080325		20.13	2.11	38.44	16.42	->		*>8 040*	
4173-116	20	080325		20.11	2.13	38.44	16.22	->		*>8 040*	
4173-117	20	080325		20.15	2.14	37.66	15.85	->		*>8 040*	
4173-118	20	080325		20.13	2.12	36.48	15.50	->		*>8 040*	

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]	
4173-169	70	081104	081118	20.07	2.13	30.40	12.80	330	Ductile		
4173-170	70	081104	081204	20.10	2.14	30.40	12.76	708	Ductile		
4173-171	70	081104	081124	20.11	2.12	29.91	12.69	476	Ductile		
4173-172	70	081104	081106	20.08	2.12	29.91	12.67	32	Ductile		
4173-173	70	081104	081127	20.12	2.13	29.91	12.63	548	Ductile		
4173-174	70	081104	081127	20.07	2.13	29.91	12.60	548	Ductile		
4173-175	70	081104	081105	20.09	2.14	29.91	12.54	26	Ductile		
4173-176	70	081104	090105	20.10	2.12	29.42	12.48	1 428	Ductile		
4173-11	70	071206	071207	20.08	2.12	29.42	12.46	4.7	Ductile		
4173-164	70	080827		20.10	2.12	29.22	12.39	->		*>4 320*	
4173-165	70	080827	090113	20.09	2.12	29.22	12.38	3 297	Ductile		
4173-166	70	080827		20.09	2.12	29.22	12.38	->		*>4 320*	
4173-167	70	080827	090209	20.09	2.12	29.22	12.38	3 955	Ductile		
4173-168	70	080827	090206	20.06	2.12	29.22	12.36	3 917	Ductile		
4173-129	70	080828	081216	20.11	2.11	28.93	12.34	2 632	Ductile		
4173-130	70	080828	081216	20.09	2.11	28.93	12.33	2 633	Ductile		
4173-131	70	080828	081229	20.08	2.11	28.93	12.32	2 928	Ductile		
4173-58	70	080225	080425	20.13	2.12	28.93	12.29	1 426	Ductile		
4173-12	70	071206	080107	20.10	2.12	28.93	12.27	723	Ductile		
4173-132	70	080828	090116	20.11	2.12	28.93	12.27	3 376	Ductile		
4173-133	70	080828	090113	20.10	2.12	28.93	12.27	3 303	Ductile		
4173-134	70	080828	090105	20.08	2.12	28.93	12.25	3 094	Ductile		
4173-135	70	080828	081103	20.06	2.12	28.93	12.24	1 576	Ductile		
4173-59	70	080225	080425	20.14	2.13	28.93	12.23	1 427	Ductile		
4173-136	70	080828	081110	20.09	2.13	28.93	12.20	1 765	Ductile		
4173-137	70	080828	081118	20.08	2.13	28.93	12.19	1 974	Ductile		
4173-60	70	080225	080623	20.14	2.10	28.34	12.17	2 780	Ductile		
4173-138	70	080828		20.10	2.10	28.34	12.15	->		*>4 296*	
4173-61	70	080225	080809	20.14	2.11	28.34	12.11	4 003	Ductile		
4173-13	70	071206	080305	20.11	2.12	28.34	12.03	2 142	Ductile		
4173-62	70	080225	080825	20.11	2.12	28.34	12.03	4 341	Ductile		
4173-63	70	080225	080808	20.14	2.13	28.34	11.98	3 956	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]	
4173-64	70	080225	081126	20.14	2.11	27.85	11.90	6 587	Ductile		
4173-14	70	071206	080508	20.08	2.11	27.85	11.86	3 696	Ductile		
4173-15	70	071206	080609	20.11	2.12	27.85	11.82	4 457	Ductile		
4173-16	70	071206	081029	20.09	2.11	27.36	11.66	7 861	Ductile		
4173-17	70	071206		20.10	2.11	27.07	11.54	->		*>10 680*	
4173-65	70	080225		20.13	2.14	27.36	11.50	->		*>8 736*	
4173-66	70	080225		20.12	2.11	26.77	11.43	->		*>8 736*	
4173-18	70	071206		20.11	2.11	26.77	11.42	->		*>10 680*	
4173-67	70	080225		20.13	2.10	26.48	11.37	->		*>8 736*	
4173-19	70	071206		20.10	2.12	26.77	11.35	->		*>10 680*	
4173-68	70	080225		20.13	2.11	26.48	11.31	->		*>8 736*	
4173-69	70	080225		20.12	2.11	26.48	11.30	->		*>8 736*	
4173-20	70	071206		20.10	2.12	26.48	11.23	->		*>10 680*	
4173-70	70	080225		20.13	2.10	26.09	11.20	->		*>8 736*	
4173-71	70	080225		20.12	2.11	26.09	11.13	->		*>8 736*	
4173-72	70	080225		20.12	2.11	26.09	11.13	->		*>8 736*	
4173-21	70	071206		20.10	2.11	26.09	11.12	->		*>10 680*	
4173-22	70	071206		20.10	2.12	26.09	11.06	->		*>10 680*	
4173-23	70	071206		20.11	2.11	25.50	10.88	->		*>10 680*	

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]	
4173-177	95	081104	081110	20.10	2.13	19.91	8.40	122	Ductile		
4173-178	95	081104	081111	20.11	2.14	19.91	8.36	167	Ductile		
4173-24	95	071210	071210	20.10	2.14	19.91	8.35	0.1	Ductile		
4173-179	95	081104	081110	20.10	2.14	19.91	8.35	131	Ductile		
4173-180	95	081104	081117	20.10	2.12	19.42	8.23	257	Ductile		
4173-181	95	081104	081117	20.09	2.12	19.42	8.23	261	Ductile		
4173-149	95	080827	080911	20.04	2.08	19.03	8.21	358	Ductile		
4173-182	95	081104	081117	20.11	2.13	19.42	8.20	254	Ductile		
4173-150	95	080827	080918	20.07	2.11	19.03	8.10	533	Ductile		
4173-151	95	080827	080919	20.05	2.11	19.03	8.09	543	Ductile		
4173-152	95	080827	080916	20.06	2.12	19.03	8.05	484	Ductile		
4173-93	95	080306	080322	20.10	2.13	19.03	8.03	386	Ductile		
4173-25	95	071210	071217	20.08	2.13	19.03	8.02	141	Ductile		
4173-153	95	080827	080923	20.06	2.10	18.63	7.97	642	Ductile		
4173-94	95	080306	080404	20.10	2.13	18.63	7.86	689	Ductile		
4173-95	95	080306	080414	20.11	2.11	18.24	7.78	886	Ductile		
4173-26	95	071210	080102	20.10	2.13	18.24	7.69	487	Ductile		
4173-96	95	080306	080415	20.10	2.11	18.04	7.69	945	Ductile		
4173-97	95	080306	080528	20.11	2.11	17.65	7.53	1 984	Ductile		
4173-98	95	080306	080508	20.12	2.09	17.26	7.44	1 505	Ductile		
4173-99	95	080306	080611	20.10	2.12	17.26	7.32	2 321	Ductile		
4173-100	95	080306	080826	20.12	2.13	17.06	7.21	4 144	Ductile		
4173-101	95	080306	080731	20.11	2.11	16.67	7.11	3 520	Ductile		
4173-27	95	071210	080322	20.10	2.14	16.67	7.00	2 450	Ductile		
4173-102	95	080306	080828	20.13	2.12	16.48	7.00	4 192	Ductile		
4173-103	95	080306	080825	20.13	2.12	16.48	7.00	4 106	Ductile		
4173-104	95	080306	081229	20.13	2.11	16.18	6.91	7 099	Ductile		
4173-105	95	080306	090130	20.10	2.13	16.18	6.83	7 924	Ductile		
4173-106	95	080306	090130	20.11	2.12	15.89	6.74	7 912	Ductile		
4173-107	95	080306		20.12	2.12	15.69	6.66	->		*>8 496*	
4173-28	95	071210	081110	20.08	2.13	15.69	6.61	8 040	Ductile		
4173-108	95	080306		20.10	2.12	15.50	6.57	->		*>8 496*	

HYDROSTATIC PRESSURE TESTING

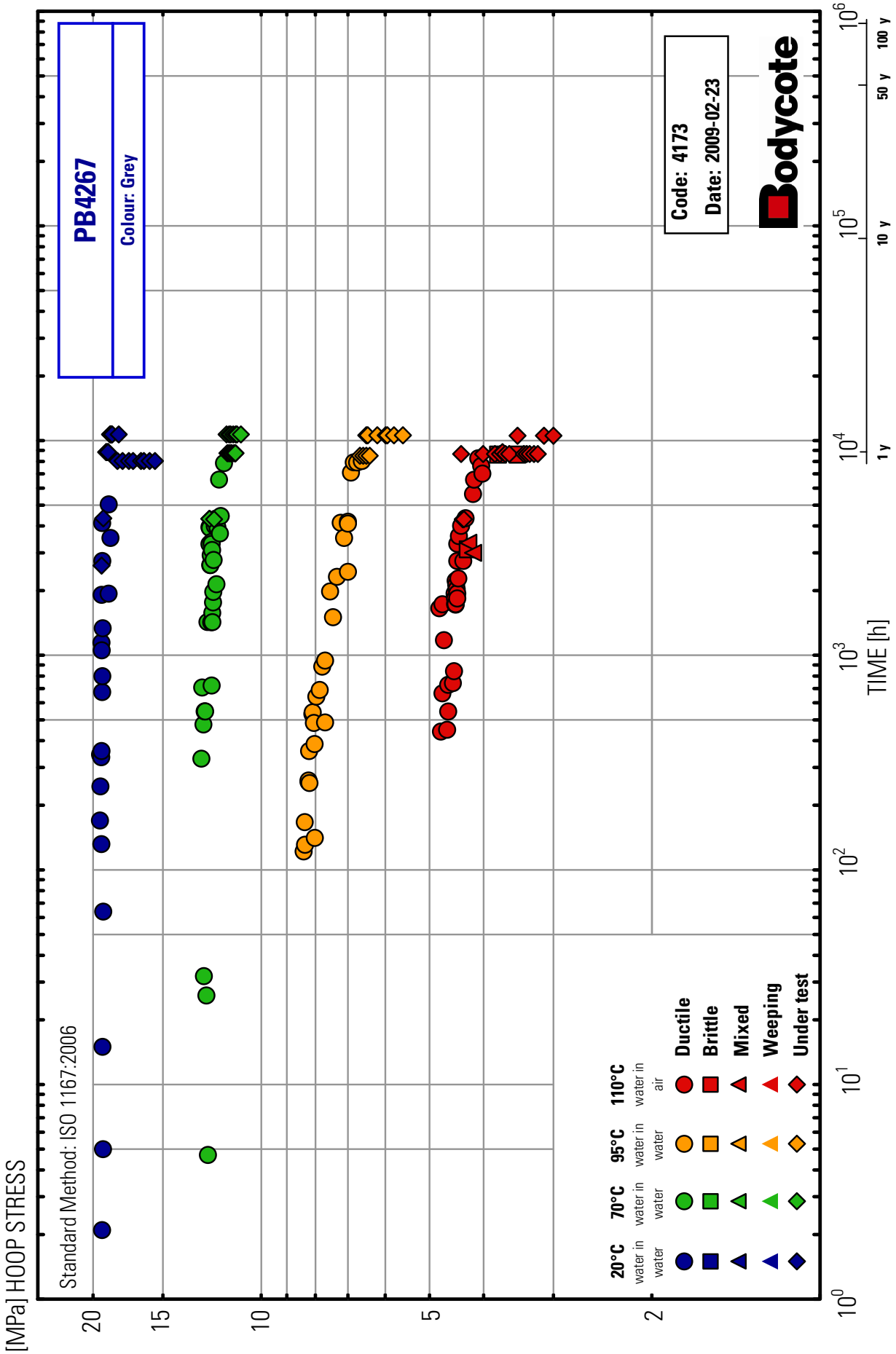
Code	T	Start date	Reg date	d_{em}	e_{min}	p	σ	Failure time	Failure mode	Test time	Remark
	[°C]	[yymmdd]	[yymmdd]	[mm]	[mm]	[bar]	[MPa]	[h]		[h]	
4173-29	95	071210		20.10	2.12	15.30	6.49	->		*>10 584*	
4173-109	95	080306		20.11	2.12	15.30	6.49	->		*>8 496*	
4173-30	95	071210		20.09	2.13	15.30	6.45	->		*>10 584*	
4173-110	95	080306		20.12	2.10	14.91	6.40	->		*>8 496*	
4173-31	95	071210		20.09	2.13	14.71	6.20	->		*>10 584*	
4173-32	95	071210		20.10	2.12	14.12	5.99	->		*>10 584*	
4173-33	95	071210		20.09	2.13	14.12	5.95	->		*>10 584*	
4173-34	95	071210		20.10	2.13	13.73	5.79	->		*>10 584*	
4173-35	95	071210		20.09	2.13	13.24	5.58	->		*>10 584*	

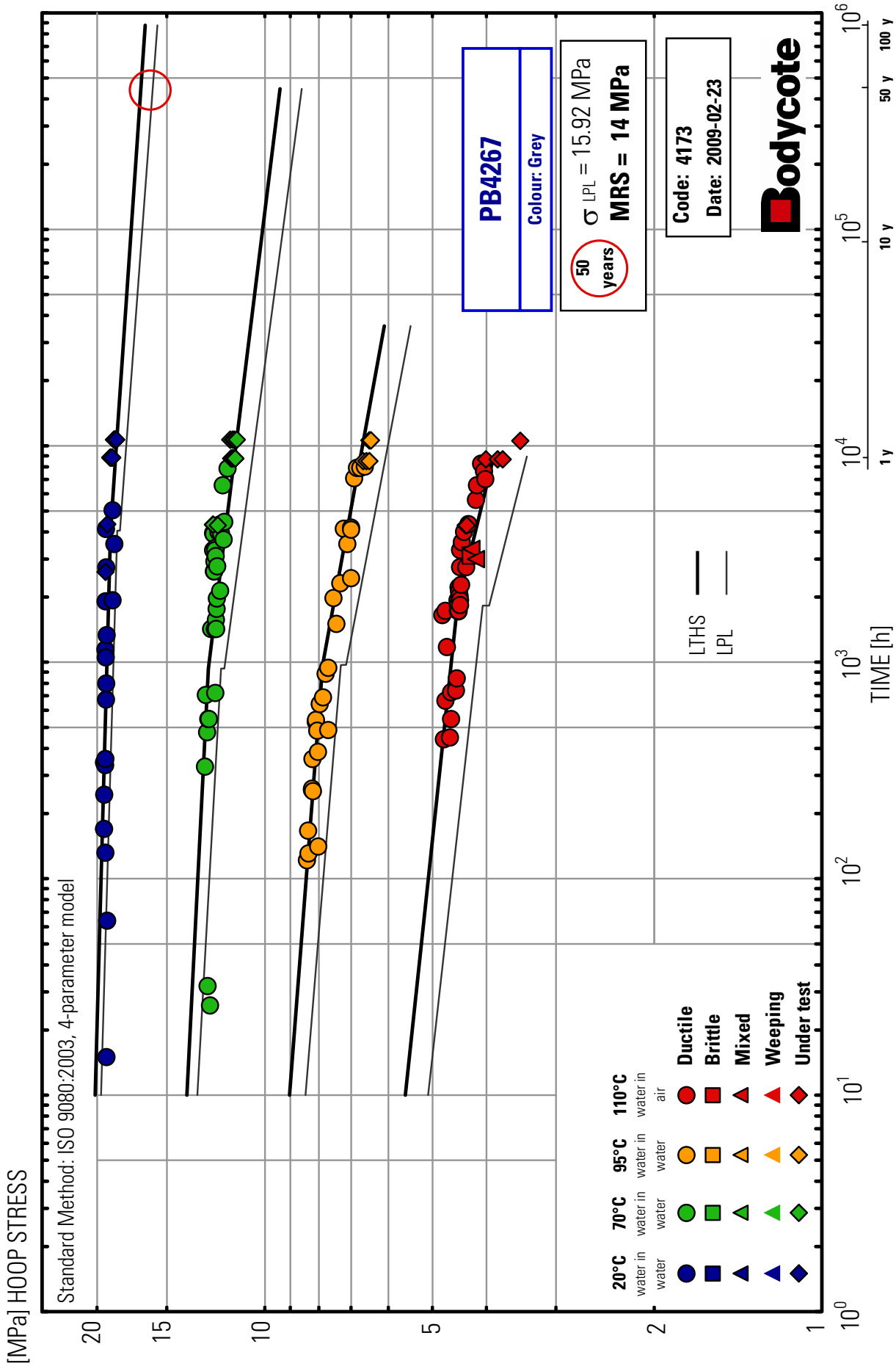
HYDROSTATIC PRESSURE TESTING

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]	
4173-36	110	071210	071211	20.12	2.10	11.57	4.97	0.1	Ductile		
4173-183	110	081104	090112	20.09	2.13	11.38	4.80	1 656	Ductile		
4173-37	110	071210	071210	20.13	2.11	11.18	4.77	0.0	Ductile		
4173-184	110	081104	081124	20.10	2.14	11.38	4.77	441	Ductile		
4173-185	110	081104	081202	20.08	2.12	11.18	4.74	665	Ductile		
4173-186	110	081104	090115	20.08	2.12	11.18	4.74	1 730	Ductile		
4173-187	110	081104	081223	20.08	2.13	11.18	4.71	1 176	Ductile		
4173-188	110	081104	081124	20.07	2.12	10.98	4.65	450	Ductile		
4173-189	110	081104	081127	20.09	2.13	10.98	4.63	547	Ductile		
4173-190	110	081104	081205	20.09	2.13	10.98	4.63	728	Ductile		
4173-154	110	080828	080929	20.06	2.13	10.79	4.54	742	Ductile		
4173-38	110	071210	071211	20.13	2.11	10.59	4.52	0.6	Ductile		
4173-120	110	080701	080805	20.13	2.11	10.59	4.52	843	Ductile		
4173-125	110	080703	080922	20.13	2.10	10.50	4.51	1 941	Ductile		
4173-119	110	080701	080911	20.14	2.12	10.59	4.50	1 733	Ductile		
4173-123	110	080703	080918	20.09	2.10	10.50	4.50	1 839	Ductile		
4173-122	110	080703	080913	20.17	2.11	10.50	4.49	1 721	Ductile		
4173-127	110	080708	080918	20.10	2.12	10.59	4.49	1 731	Ductile		
4173-128	110	080708	081009	20.10	2.12	10.59	4.49	2 225	Ductile		
4173-124	110	080703	080930	20.12	2.11	10.50	4.48	2 127	Ductile		
4173-126	110	080708	081001	20.11	2.13	10.59	4.47	2 031	Ductile		
4173-121	110	080703	080922	20.12	2.12	10.50	4.46	1 941	Ductile		
4173-155	110	080828	081113	20.06	2.13	10.59	4.46	1 840	Ductile		*1*
4173-156	110	080828	090113	20.06	2.13	10.59	4.46	3 304	Ductile		
4173-157	110	080828	080908	20.06	2.13	10.59	4.46	266	Weeping		*1*
4173-158	110	080828	081222	20.06	2.13	10.59	4.46	2 752	Ductile		
4173-159	110	080828	081201	20.07	2.14	10.59	4.44	2 280	Ductile		
4173-160	110	080828	090126	20.05	2.14	10.59	4.43	3 594	Ductile		
4173-73	110	080228		20.09	2.11	10.30	4.39	->		*>8 664*	
4173-74	110	080228	080813	20.09	2.11	10.30	4.39	4 013	Ductile		
4173-162	110	080828		20.09	2.12	10.30	4.36	->		*>4 296*	
4173-163	110	080828	081222	20.05	2.12	10.30	4.35	2 752	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]	
4173-161	110	080828		20.07	2.13	10.30	4.34	->		*>4 296*	
4173-75	110	080228	080827	20.10	2.11	10.10	4.31	4 350	Ductile		
4173-39	110	071210	080421	20.13	2.11	10.00	4.27	3 116	Brittle		
4173-76	110	080228	080717	20.10	2.11	10.00	4.26	3 340	Mixed		
4173-77	110	080228	080702	20.10	2.11	9.81	4.18	2 998	Mixed		
4173-78	110	080228	081020	20.10	2.11	9.81	4.18	5 638	Ductile		
4173-79	110	080228	081128	20.10	2.12	9.81	4.16	6 574	Ductile		
4173-80	110	080228	090209	20.09	2.11	9.61	4.09	8 274	Ductile		
4173-81	110	080228	090112	20.11	2.12	9.51	4.04	7 625	Ductile		
4173-40	110	071210	080929	20.13	2.13	9.51	4.02	7 020	Ductile		
4173-82	110	080228		20.10	2.15	9.61	4.01	->		*>8 664*	
4173-83	110	080228		20.09	2.12	9.02	3.82	->		*>8 664*	*2*
4173-41	110	071210	081203	20.13	2.11	8.83	3.77	8 610	Brittle		*1, 3*
4173-84	110	080228		20.11	2.12	8.83	3.74	->		*>8 664*	*2*
4173-85	110	080221		20.10	2.10	8.63	3.70	->		*>8 832*	*2*
4173-86	110	080228		20.10	2.10	8.53	3.66	->		*>8 664*	
4173-87	110	080228		20.09	2.13	8.53	3.60	->		*>8 664*	*2*
4173-42	110	071210	081203	20.14	2.13	8.24	3.48	8 606	Brittle		*3*
4173-43	110	071212		20.14	2.13	8.24	3.48	->		*>10 536*	*2*
4173-88	110	080228		20.10	2.13	8.04	3.39	->		*>8 664*	*2*
4173-44	110	071212	080910	20.13	2.10	7.85	3.37	-	Stopped		*2, 4*
4173-89	110	080228		20.12	2.11	7.85	3.35	->		*>8 664*	*2*
4173-90	110	080228		20.09	2.13	7.85	3.31	->		*>8 664*	*2*
4173-45	110	071212	080910	20.12	2.11	7.65	3.26	-	Stopped		*2, 4*
4173-91	110	080228		20.12	2.12	7.65	3.25	->		*>8 664*	*2*
4173-92	110	080228		20.12	2.10	7.45	3.20	->		*>8 664*	*2*
4173-46	110	071212		20.12	2.12	7.36	3.12	->		*>10 536*	*2*
4173-47	110	071212		20.15	2.12	7.06	3.00	->		*>10 536*	*2*


PB4267
Colour: Grey
Code: 4173
Date: 2009-02-23
Bodycote
Standard Method: ISO 1167:2006
[MPa] HOOP STRESS
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
70°C water in water
95°C water in water
110°C water in air
Ductile
Brittle
Mixed
Weeping
Under test


[MPa] HOOP STRESS
Standard Method: ISO 9080:2003, 4-parameter model
TIME [h]
LTHS
LPL
PB4267
Colour: Grey
σ LPL = 15.92 MPa
MRS = 14 MPa
50 years
Code: 4173
Date: 2009-02-23
Bodycote
20°C water in water
70°C water in water
95°C water in water
110°C water in air
Ductile
Brittle
Mixed
Weeping
Under test
1 y
10 y
50 y
100 y

BODYCOTE/P-09/53

DETERMINATION OF THE LONG-TERM HYDROSTATIC STRENGTH
ISO 9080:2003-evaluation of the PB pipe compound PB4267 Grey from LYONDELLBASELL INDUSTRIES

Mattias SVEDBERG

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