Bodycote Report

EVALUATION ACCORDING TO ASTM F 2023

Evaluation of the chlorine resistance according to ASTM F 2023 of the PB pipe material PB4267 GREY

Mattias Svedberg

SE-611 82 Nyköping,Sweden
Phone +46 155 22 14 76
Fax +46 155 26 31 25
E-mail info@bodycotepolymer.com

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Handled by:
Mattias Svedberg

Basell Polyolefine GmbH
Industriepark Höchst, D 536
65926 Frankfurt (M)
Germany

Tech contact: Dr. Klaus Könnecke

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Abstract

Basell Polyolefine GmbH has initiated a test program in order to evaluate the chlorine resistance of PB pipe material PB4267 GREY according to ASTM F 2023.

12 pipe specimens have been started at 95, 105 and 115°C. The chlorine level was set to 4 ppm and the pH level to 6.8.

Calculations of the estimated time-to-failure according to ASTM F 2023 have been performed. The table below shows the estimated times to failure for the condition called Traditional Domestic (CI-TD) and Domestic Continuous Re-circulation (CI-R).

Condition	Temperature	Hoop stress	Service time fraction	Estimated time to failure
Traditional domestic (CI-TD)	23°C (73°F)	2.20 MPa	75%	253 years
	60°C (140°F)	2.20 MPa	25%	
Domestic Continuous Re-circulation (CI-R)	60°C (140°F)	2.20 MPa	100%	65 years

All estimations in this report are only valid for the investigated PB pipe material PB4267 GREY with the Bodycote code 3527.

LIST OF CONTENTS

Report written by

Mattias Svedberg
Operations Manager

Reviewed by

Joakim Jansson
Project Manager

Approved by

Jarno Hassinen
Technical Manager

1 Aim of the project

The aim of this project was to evaluate the effect of chlorinated water on the lifetime of PB pipe material PB4267 GREY delivered by Basell. The method of approach has been ASTM F 2023.

1.1 Summary of the ASTM F 2023 test method[1]

The PEX tubing or tubing/fitting assemblies are exposed to pressurized test-fluid until failure. All time-to-fail data used for analysis shall be the result of oxidative degradation (Stage III). A minimum number of test temperature and hoop stress conditions are required to allow accurate data analysis and time-to-failure extrapolations.

NOTE 2—The procedures described in this test method (with some modifications of test temperatures or stresses, or both) have been used to evaluate pipes manufactured from polybutylene (PB), polyethylene (PE), polypropylene (PP), multilayer (polymer-metal composite), copper, and stainless steel.

1.2 Bodycote Polymer approach

Bodycote Polymer applies the ASTM F 2023 as follows; the tubing is tested at three temperatures (95, 105 and 115°C) and at two different pressure levels at each temperature with the aim to only generate Stage III failures. If a failure occurs that cannot be classified as Stage III, pipes will be started at a lower pressure level in order to allow accurate data analysis.

When an accurate data set has been achieved, it is analyzed using ISO 9080, 3- and 4-parameter models. The model with the best fit is then used for the time-to-failure extrapolations applying the given service conditions in ASTM F 2023.

1.3 Failure types

ASTM F 2023 requires that all data used for analysis shall be the result of environmental or oxidative degradation (Stage III). This report refers to Stage III failures as brittle failures.

[1] Recitation from ASTM F 2023

2 Investigated pipe material

Basell delivered the 16 mm SDR[2] 9 PB pipe material, PB4267 GREY. All pipes show good visual appearance. The results obtained regarding the dimensions are shown in Table 1. All pipes showed small variations in the specific dimensions. Further information about the material is presented in Appendix B.

Table 1 *Dimension measurements results*

Code	**Outer diameter**		**Min wall thickness**		**Max wall thickness**	
	Mean[3]	**s**[4]	**Mean**	**s**	**Mean**	**s**
	mm	*mm*	*mm*	*mm*	*mm*	*mm*
3527	16.12	0.01	1.84	0.01	2.02	0.01

[2] *Standard Dimension Ratio*
[3] *Mean value*
[4] *Standard deviation value*

3 Experimental procedure

All tests have been performed at Bodycote Polymer, Sweden, and in accordance with ASTM F 2023.

3.1 Chlorine circulation loop

The components in the circulation loop are made of inert materials such as titanium, PVDF and PTFE. In the chlorine dosage unit, PE, PVC and PP components have been used. The fittings are made from PFA. The chlorine is produced using sodium hypochlorite at a known pH.

The test fluid is continuously purified after sample exposure through a state of the art filtering system including Reverse Osmosis (RO) to avoid contamination of the test fluid.

The pipes have been tested in series (vertically), i.e. the pipe ends are unrestrained and allowed to freely expand bi-directionally.

Table 2 *Accuracy of temperature and pressure*

Property	Value
Temperature accuracy, inside	±1°C
Temperature accuracy, outside	±2.5°C
Pressure accuracy	±0.2 bar

Table 3 *Measured test parameters*

Property	Set value	*Average*	*s*[5]
pH	6.8	*6.83*	*0.08*
Chlorine level (inlet)	4.0 ppm	*3.97 ppm*	*0.08 ppm*
ORP[6]	≥825 mV	*878 mV*	*15 mV*
Volume flow	54 dm^3/h[7]	-	-

[5] *Standard deviation*

[6] *Oxidation reduction potential*

[7] *Corresponds to 0.13 m/s for a 1/2" SDR 9 pipe*

4 Extrapolation techniques

To predict the lifetime under constant conditions is multiple linear regression according to ISO 9080 used (conditions I-III)[8]. When the pipes are exposed to different operational conditions the multiple regression analysis is combined with Miner's rule (condition IV).

4.1 Multiple linear regression

The multiple linear regression method used for the determination of the time to failure (t_{fi}) is based on ISO 9080. The 4-parameter model contains four regression coefficients C_1-C_4 and two independent variables, temperature (T_i) and stress (σ_i). For the 3-parameter model is C_3=0.

Equation 1 *The 4-parameter model according to ISO 9080*

$$Log(t_{fi}) = C_1 + C_2 \cdot \frac{1}{T_i} + C_3 \cdot Log(\sigma_i) + C_4 \cdot \frac{Log(\sigma_i)}{T_i}$$

Equation 1 can be used for calculations of the expected failure time at any fixed combination of temperature and pressure (hoop stress) under constant service conditions.

4.2 Miner's rule

Assuming that each damage (caused by a constant service condition) is proportional to the duration of attack ("proportionality rule") and the damages from different service conditions "i" may be cumulatively added ("additivity rule") Miner's rule appears in ISO 13760 as:

Equation 2 *Miner's rule according to ISO 13760*

$$\frac{1}{t_f} = \sum_{i=1}^{i=n} \left[\frac{t_i / t_{tot}}{t_{fi}(T_{i,}\sigma_i)} \right]$$

Where:

t_f	Lifetime at various conditions
$t_{fi}(T_i,\sigma_i)$	Failure time for condition "i"
n	Number of service conditions
t_i	Exposure time at condition "i"
t_{tot}	Total exposure time

The combination of equations 1 and 2 provides the tool for the determination of the expected lifetime of plastic materials subjected to varying service conditions, i.e. alterations in temperature and pressure.

[8] Refer to paragraph 6

5 Results from the chlorine circulation loop testing

12 pipe specimens were started of the PB pipe material PB4267 GREY (code 3527) at 95, 105 and 115°C. The internal medium was chlorinated water of 4 ppm and the external medium was air. The results are presented in Appendix B and shown in Appendix C.

All pipes started have whitened inner surfaces and failed in a brittle manner.

5.1 Testing at 95°C

At 95°C two pipes were started at each pressure level of 6.0 and 4.5 bar. The average failure times are 13 350 h and 15 922 h, respectively.

5.2 Testing at 105°C

At 105°C two pipes were started at each pressure level of 4.5 and 3.0 bar. The average failure times are 5 292 h and 8 183 h, respectively.

5.3 Testing at 115°C

At 115°C two pipes were started at each pressure level of 4.5 and 2.5 bar. The average failure times are 2 754 h and 3 111 h, respectively.

6 Evaluation according to ASTM F 2023

According to the ASTM F 2023, the estimated time-to-failure shall be calculated at a hoop stress corresponding to a sustained internal pressure of 5.5 bar (80 psi) for the standard dimension ratio (SDR)[9] of the tested specimens, see Table 3, at the following temperature exposure conditions;

I. 100% of the total time at 23°C (73°F)

II. 100% of the total time at 60°C (140°F) aka CI-R

III. 100% of the total time at 82°C (180°F)

IV. 25% of the total time at 60°C (140°F) and 75% at 23°C (73°F) aka CI-TD

The conditions II and IV are often referred to as *Domestic continuous re-circulation (CI-R)* and *Traditional domestic (CI-TD)*, respectively.

For the conditions I-III the lifetime predictions will be done using multiple linear regression, for condition IV Miner's rule will also be applied.

6.1 Extrapolation hoop stress

The extrapolation hoop stress is based on the dimension ratio for the tested pipe. The following equation is used:

Equation 3 *Hoop stress equation*

$$\sigma = P \cdot \left(\frac{SDR - 1}{2} \right)$$

Where:

σ	Extrapolation hoop stress
P	Internal pressure
SDR	Standard dimension ratio

Applying equation 3 to the tested material (SDR 9) at a pressure of 5.5 bar, gives an extrapolation hoop stress of 2.20 MPa.

Table 4 *Extrapolation hoop stress for the investigated material*

Code	Nominal dimension	Standard dimension ratio (SDR)	Internal pressure	Extrapolation hoop stress
3527	16 x 1.8 mm	9	5.5 bar	**2.20 MPa**

[9] *SDR is a selected series of numbers in which the average outside diameter to minimum wall thickness dimension ratios are constant for all sizes of tubing in each standard dimension ratio, and which are the ANSI Z17.1 Preferred Number Series R10 modified by +1.*

6.2 Multiple linear regression analysis

The regression analysis has been performed only using oxidative failure data, see Appendix B. Both the 3- and 4-parameter models have been applied, finally the 3-parameter model was chosen.

The analysis is based on all of the 12 data points, see Appendix B.

Table 5 *Result from the regression analysis performed according to ISO 9080 using the 3-parameter model.*

Code	Correlation (R^2)	C_1	C_2	C_3	C_4
3527	0.980	-11.216	5 718.426	0	-189.425

According to ASTM F 2023 shall the correlation coefficient (R^2) be >0.9. This requirement is fulfilled for the regression analysis of code 3527.

6.3 Lifetime calculations

The results from the calculations of the estimated time to failure for the different conditions stated in ASTM F 2023 are presented in Table 6 below.

Table 6 *Results from the lifetime calculations according to ASTM F 2023 for the pipe code 3527*

Condition	Temperature	Hoop stress	Service time fraction	Estimated time to failure
I	23°C (73°F)	2.20 MPa	100%	>500 years
II (CI-R)	60°C (140°F)	2.20 MPa	100%	65 years
III	82°C (180°F)	2.20 MPa	100%	5.6 years
IV (CI-TD)	23°C (73°F)	2.20 MPa	75%	253 years
	60°C (140°F)	2.20 MPa	25%	

7 Additional comments

The delivered pipes showed no visual defects and no unusual behaviour were observed during the pressure testing of the PB pipe material PB4267 GREY.

8 Referred documents

ASTM F 2023 - 05
Standard Test Method for Evaluating the Oxidative Resistance of Crosslinked Polyethylene (PEX) Tubing and Systems to Hot Chlorinated Water

ISO 9080:2003
Plastics piping and ducting systems - Determination of the long-term hydrostatic strength of thermoplastics materials in pipe form by extrapolation

ISO 13760:1998
Plastics pipes for the conveyance of fluids under pressure - Miner's rule - Calculation method for cumulative damage

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Client info

Client:	Basell Polyolefine GmbH
Street adress:	Industriepark Höchst, D 536
Postal code:	65926 Frankfurt (M)
Country:	Germany
Contact person:	Dr. Klaus Könnecke
Phone:	+49(0)69-305 351 59
Fax:	+49(0)69-305 177 72
Mail:	klaus.koennecke@basell.com
Web:	www.basell.com

Material info

Bodycote code:	3527
Trade name:	PB4267 Grey
Material:	PB
Colour:	Grey
Nominal dimension:	16 x 1.8 mm
Arrival date at Bodycote:	2005-01-26
Amount:	62 x 1.2 m
Cosignor:	Basell Polyolefine GmbH
Marking:	n/a
Resin producer (date, batch no.):	Basell Polyolefine GmbH (n/a)
Pipe producer (date, lot no.):	n/a

Test info

Test laboratory:	Bodycote Polymer			
Responsible:	Michael Falkhäll and Urban Westberg			
Test method:	ASTM F 2023-05			
Length (total/free):	350/300 mm			
Fittings:	PFA fittings			
Internal medium:	Chlorinated water			
External medium:	Air			
Conditioning time:	1 hour			
Flow rate:	54 dm^3/h			
Chlorine source:	Sodium hypchlorite (NaOCl)			
Chlorine level:	Average	3.97 ppm	Standard deviation	0.08 ppm
pH:	Average	6.83	Standard deviation	0.08
ORP:	Average	878 mV	Standard deviation	15 mV

Table remarks

Code	Internal Bodycote code
T	Test temperature
Date	Start date
e_{min}	Minimum wall thickness
d_{em}	Mean outside diameter
p	Internal pressure
σ	Circumferential stress (hoop stress)
->	The pipe is under test

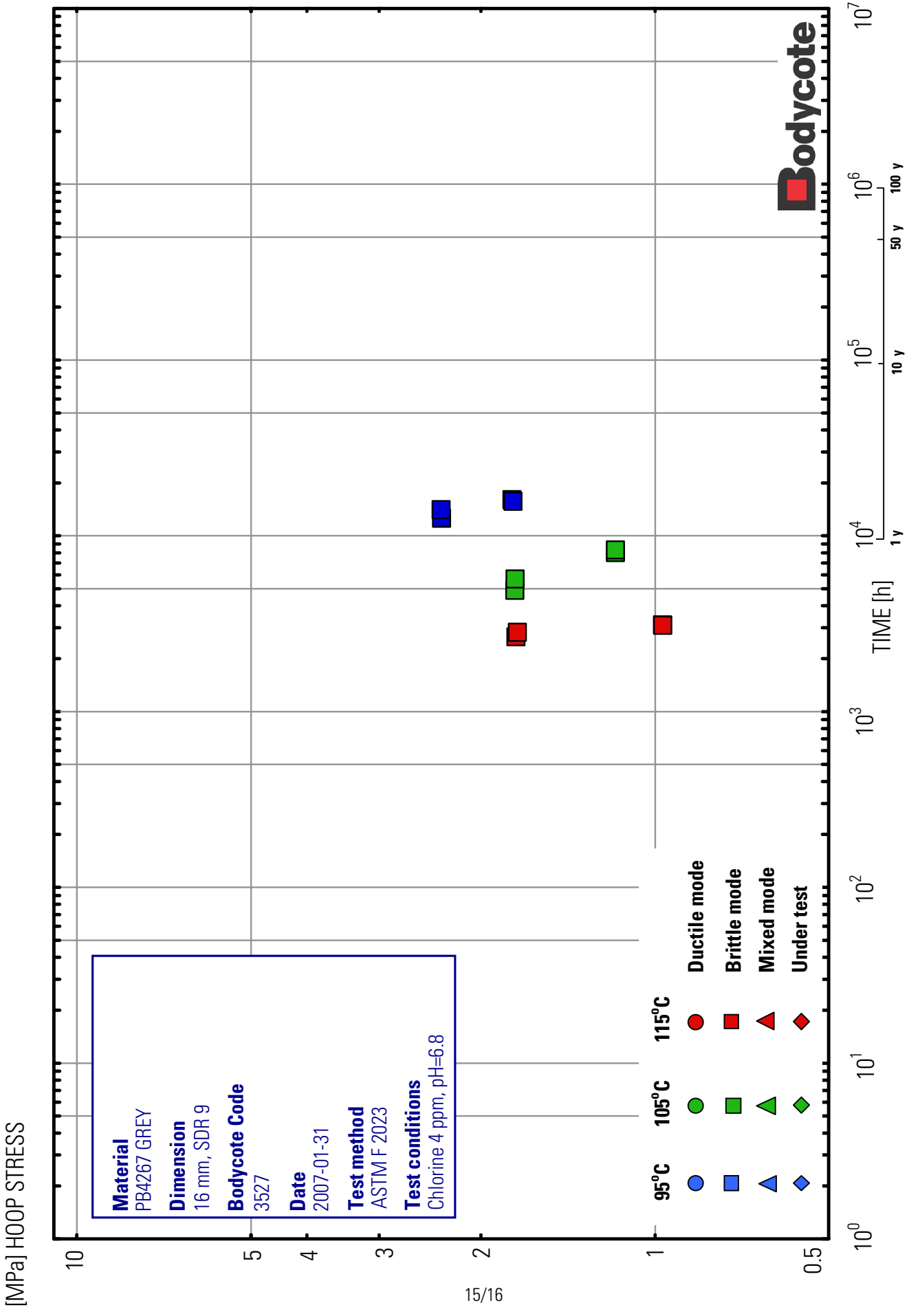
Pipe remarks

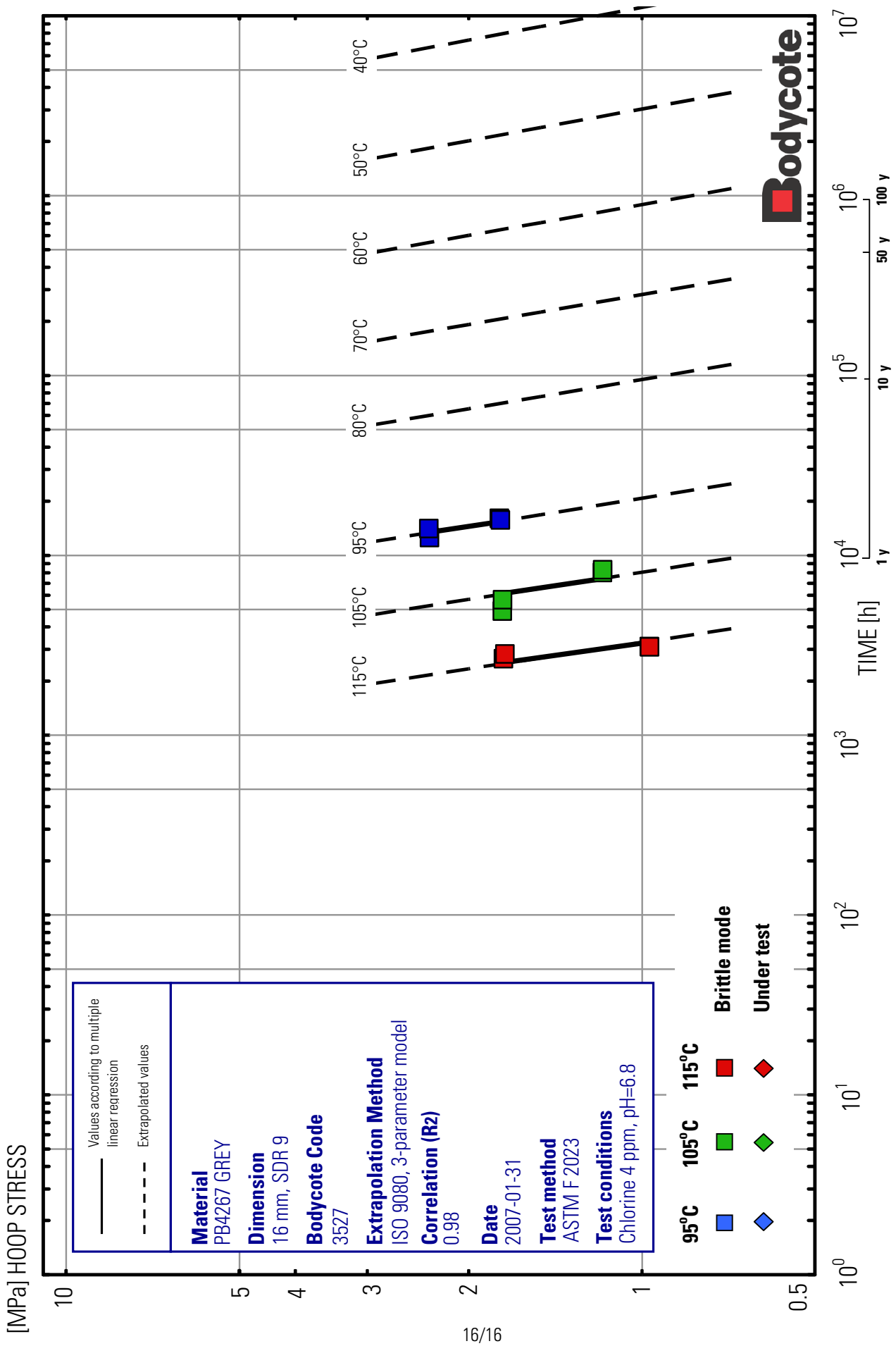
No remarks

2007-01-31

Testing with chlorinated water

Code	T [°C]	Date [yymmdd]	d_{em} [mm]	e_{min} [mm]	p [bar]	σ [MPa]	Failure time [h]	Failure mode	Test time	Remark
3527-3	95	050218	16.12	1.83	6.0	2.34	12 587	Brittle		
3527-4	95	050218	16.12	1.83	6.0	2.34	14 112	Brittle		
3527-1	95	050218	16.12	1.82	4.5	1.77	16 099	Brittle		
3527-2	95	050218	16.14	1.83	4.5	1.76	15 745	Brittle		
3527-7	105	050221	16.12	1.84	4.5	1.75	4 901	Brittle		
3527-8	105	050221	16.12	1.84	4.5	1.75	5 682	Brittle		
3527-5	105	050221	16.12	1.83	3.0	1.17	8 039	Brittle		
3527-6	105	050221	16.11	1.83	3.0	1.17	8 327	Brittle		
3527-11	115	050221	16.13	1.84	4.5	1.75	2 671	Brittle		
3527-12	115	050221	16.11	1.85	4.5	1.73	2 837	Brittle		
3527-9	115	050221	16.12	1.84	2.5	0.97	3 120	Brittle		
3527-10	115	050221	16.12	1.84	2.5	0.97	3 101	Brittle		


[MPa] HOOP STRESS
10
5
4
3
2
1
0.5
10^0
10^1
10^2
10^3
10^4
10^5
10^6
10^7
TIME [h]
1 y
10 y
50 y
100 y
Bodycote
Material
PB4267 GREY
Dimension
16 mm, SDR 9
Bodycote Code
3527
Date
2007-01-31
Test method
ASTM F 2023
Test conditions
Chlorine 4 ppm, pH=6.8
95°C
105°C
115°C
Ductile mode
Brittle mode
Mixed mode
Under test


[MPa] HOOP STRESS
TIME [h]
Bodycote
Values according to multiple linear regression
Extrapolated values
Material
PB4267 GREY
Dimension
16 mm, SDR 9
Bodycote Code
3527
Extrapolation Method
ISO 9080, 3-parameter model
Correlation (R2)
0.98
Date
2007-01-31
Test method
ASTM F 2023
Test conditions
Chlorine 4 ppm, pH=6.8
95°C 105°C 115°C
Brittle mode
Under test
115°C
105°C
95°C
80°C
70°C
60°C
50°C
40°C
1 y
10 y
50 y
100 y

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Bodycote Polymer · SE-611 82 Nyköping · Sweden
Phone +46 155 22 14 76 · Fax +46 155 26 31 25
www.bodycotepolymer.com · info@bodycotepolymer.com

Bodycote POLYMER