Securing a 100+ Year Design Lifetime for PVC-U Pressure Pipes

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Introduction

- Field observations over decades have demonstrated that the service life of PVC-U pipe systems for the transport of pressurized water can far exceed the 50-year design lifetime secured by the product standards, by maintaining the original design conditions.
- Being part of a comprehensive project aiming to clarify the relationships between processing temperature, gelation degree and long-term pressure resistance of PVC-U pipes, the present study aims to define the processing conditions allowing to reach a design lifetime of minimum 100 years.

Part I

PVC-U PIPE COMPOUND COMPOSITION & MIXING

PVC-U pipe compound composition and mixing

Component	Reference	Supplier	Dosage (p.h.r.)	Comments
S-PVC (K66-68)	Solvin 267 RC	Ineos Inovyn Ltd.	100	Bulk density: 0.58g/cc Viscosity index: 67
Filler (Coated chalk)	Lubricarb 3TS	Minera del Santo Angel, S.L.	6	Coated Calcium Carbonate D50: 2.6μm
Additives (incl.pigment)	Cores SZ 7011	Asua Products, S.A.	3,2	Ca/Zn 'one-pack' stabiliser

- The components of the mixture are pre-weighted and added into a two-stage hot (vertical) & cold (horizontal) mixer where mineral filler and additives are first well dispersed into the PVC powder that heats up to 120°C, and then slowly cooled down to 55°C. The ready-to-use compound (premix) is not sieve-screened prior to silo storage.

Part II

PVC-U PIPE EXTRUSION CONDITIONS

Extrusion samples PVC-U pipes DN140x5,4mm PN10 (C=2,0) ISO 1452-2

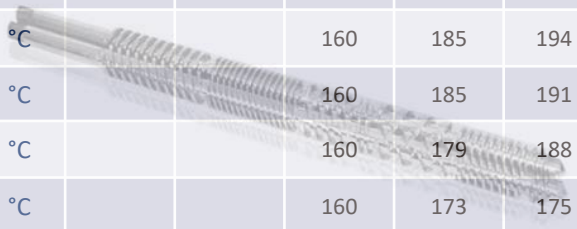
PVC-U DN140x5.4mm PN10		Time/Test Reference				
Cincinnati Milacron CM80 SC		9:12	10:54	12:40	14:03	15:37
Parameter	Unit	05 (175°C)	06 (180°C)	07 (185°C)	08 (190°C)	09 (195°C)
Dosing screw speed	rpm	18.6	21.1	23.5	26.5	29.2
Screw speed	rpm	8.1	8.1	9	9.8	11.1
Charge	%	73	81	76	77	74
Vacuum	bar	-0.9	-0.9	-0.9	-0.9	-0.9
Zone 1 Extruder	°C	150	148	175	185	183
Zone 2 Extruder	°C	165	164	166	175	186
Zone 3 Extruder	°C	160	159	163	170	179
Zone 4 Extruder	°C	155	155	162	166	169
Zone 5 Extruder	°C	152	152	153	161	162
T_{melt}	°C	174/6	180/1	184	190/1	194/5
P_{melt}	bar	178/9	203	189	199/202	189

PVC-U DN140x5.4mm PN10		Time/Test Reference				
Cincinnati Milacron CM80 SC		9:12	10:54	12:40	14:03	15:37
Parameter	Unit	05 (175°C)	06 (180°C)	07 (185°C)	08 (190°C)	09 (195°C)
Zone 1 Die-head	°C	161	162	168	164	165
Zone 2 Die-head	°C	176	175	178	179	179
Zone 3 Die-head	°C	190	190	190	190	189
Zone 4 Die-head	°C	180	180	186	181	183
Zone 5 Die-head	°C	199	196	198	194	200
Zone 6 Die-head	°C	202	196	205	200	207
Pipe-meter-weight	Kg/m	3.310	3.298	3.334	3.322	3.322
Output	Kg/h	160.8	184	202	227.2	249.1
Line speed	m/min	0.81	0.93	1.01	1.14	1.25

- ✓ Conical twin screw extruder 80 mm
- ✓ Inverted cylinder temperature profile
- ✓ Output from 160 to 250 kg/h

Extrusion samples PVC-U pipes DN140x5,4mm PN10 (C=2,0) ISO 1452-2

PVC-U DN140x5.4mm PN10		Time/Test Reference				
Krauss Maffei KMD 2 130 26D				12:20	16:50	18:30
Parameter	Unit			03b (185°C)	04b (190°C)	05b (195°C)
Dosing screw speed	rpm			35	38.6	46.9
Screw speed	rpm			17.3	17.3	21
Charge	%			68	63	65
Vacuum	bar			-0.9	-0.9	-0.9
Zone 1 Extruder	°C			163	185	197
Zone 2 Extruder	°C			160	185	194
Zone 3 Extruder	°C			160	185	191
Zone 4 Extruder	°C			160	179	188
Zone 5 Extruder	°C			160	173	175
Zone 6 Extruder	°C			155	163	165
Die-head Adaptor	°C			155	160	160
Tmelt	°C			188	194	197
Pmelt	bar			221	195	198



PVC-U DN140x5.4mm PN10		Time/Test Reference				
Krauss Maffei KMD 2 130 26D				12:20	16:50	18:30
Parameter	Unit			03b (185°C)	04b (190°C)	05b (195°C)
Zone 1 Die-head	°C			165	165	165
Zone 2 Die-head	°C			175	176	177
Zone 3 Die-head	°C			192	192	192
Zone 4 Die-head	°C			184	184	184
Zone 5 Die-head	°C			200	200	200
Zone 6 Die-head	°C			205	205	205
Pipe-meter-weight	Kg/m			3.229	3.248	3.255
Output	Kg/h			252.6	279.2	339.2
Line speed	m/min			1.30	1.43	1.74

- ✓ Parallel twin screw extruder 130 mm/26D
- ✓ Inverted cylinder temperature profile
- ✓ Output from 250 to 340 kg/h

Part III

LONG-TERM HYDROSTATIC PRESSURE TEST PROGRAMME

Long-term hydrostatic pressure testing programme (T=20ºC)

Sample	T_{melt}	Pressure testing (h)			
Ref.	(°C)	40MPa	37MPa	35MPa[(1)(2)]	31,87MPa[(3)]
05	*176*	32.8/33.4/32.7	149/275/283	498/630/656	9388/9388/9102
06	*181*	20.3/22.5/20.4	213/241/312	476/502/524	9388/9388/9216
07	*184*	26.1/27.1/28.1	187/304/232	427/493/642	9093/9328/10359
08/01b	*191*	17/13/15.1	232/219/239	632/645/716	6446/6051/6553
09 /02b	*195*	18.7/16.4/18.4	288/248/227	628/1006/1281	3298/5550/7208

Notes:
(1) TEPFFA Control points
(2) ISO 1452-1 100 h test
(3) ISO 1452-1 1000 h test

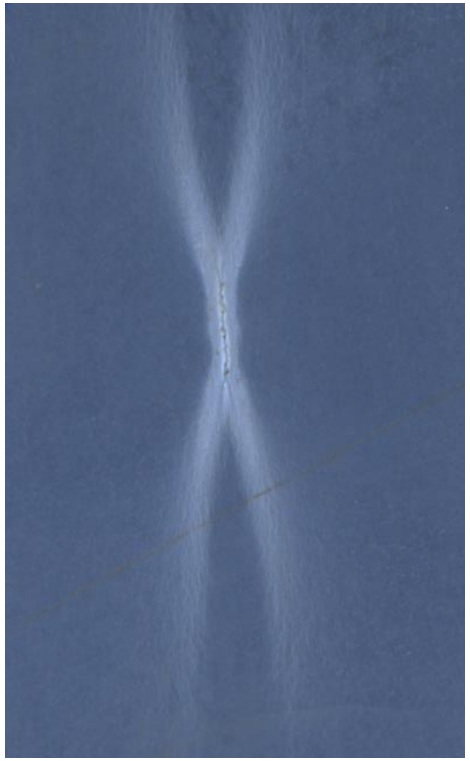
Long-term hydrostatic pressure testing programme (T=60ºC)

Sample	T_{melt}	Pressure testing (h)				
Ref.	(°C)	19MPa	17MPa	15MPa	13,5MPa	11,95MPa[(1)(2)]
05	176	8.8/7/6.5	160/135/133	257	NA	*1000/1000/1000*
06	181	6.5/7.7/8.8	89/55/102	665	NA	*1000/1000/1000*
07/ *3b*	184/ *188*	6.6/6.6/6.8	116/122/110	*321/470/493*	1503/**1515**/**1597**	NA
08/ *4b*	191/ *194*	7.4/6.2/6.3	120/114/131	*400/453/476*	3339/3848/4160 /**4999**	2285/2285/2285
09/ *5b*	195/ *197*	6.2/9.7/5.4	78/127/138	273/308/371	4103/4993/**5082**	2285/2285/2285

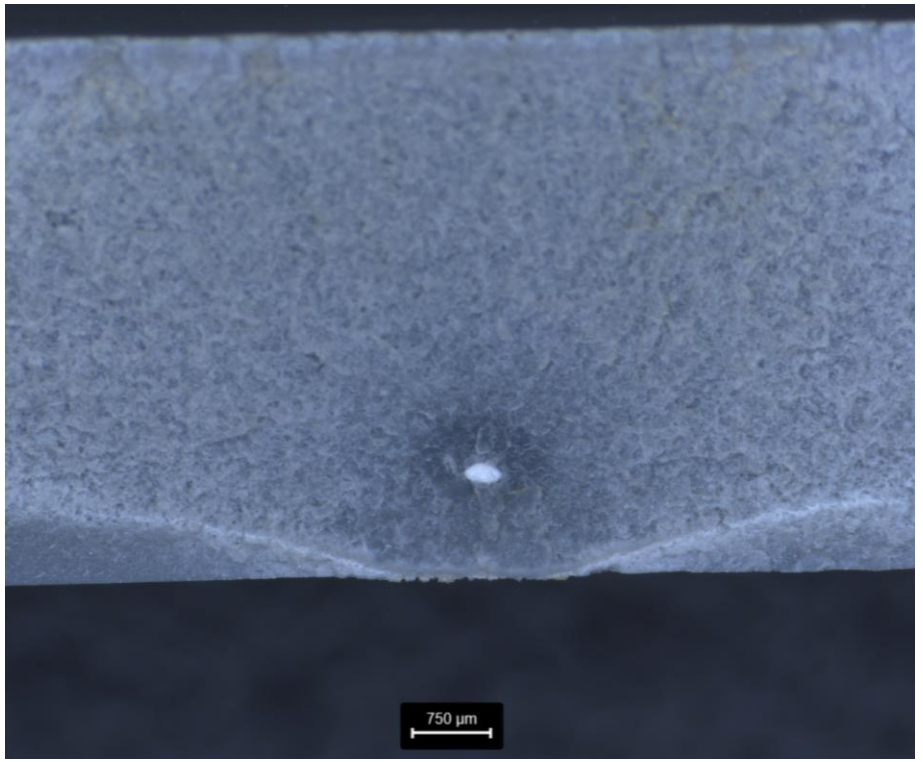
Notes:
(1) TEPFFA Control points
(2) ISO 1452-1 100 h test

Investigation brittle failure test sample PLA090/23.04.05(4999h)

Crack failure



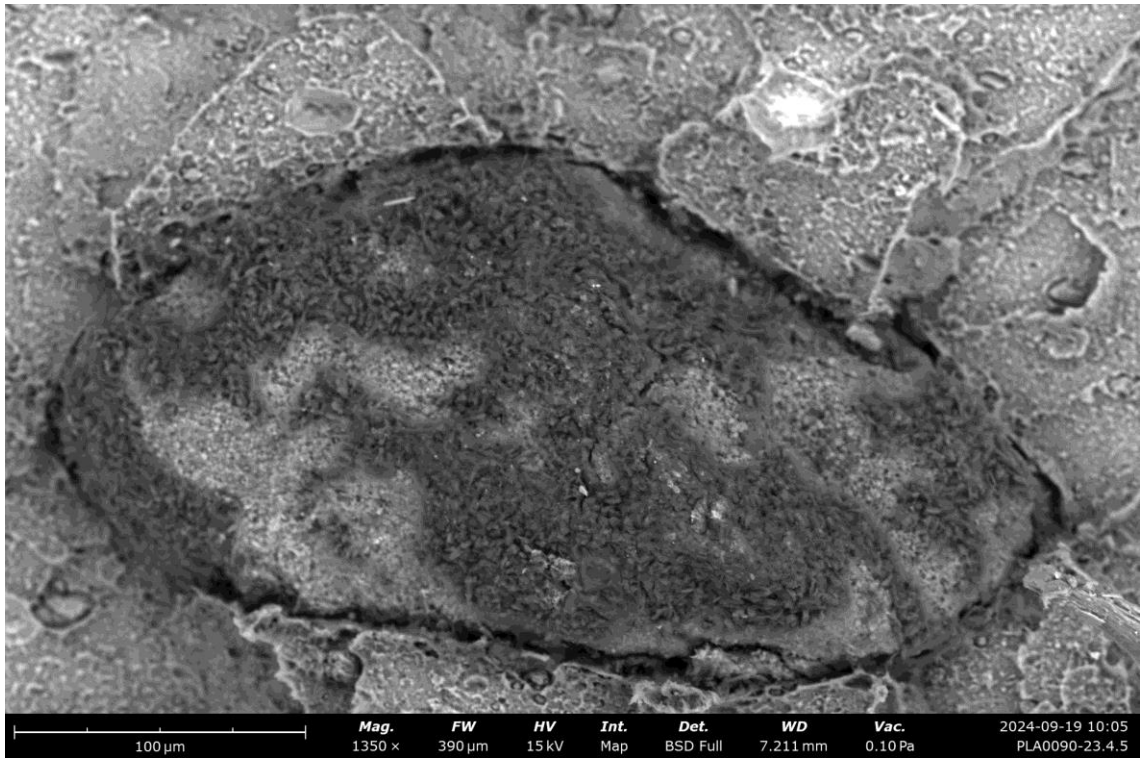
Internal surface



Longitudinal cut, white particle 330µm

Investigation brittle failure test sample PLA090/23.04.05(4999h)

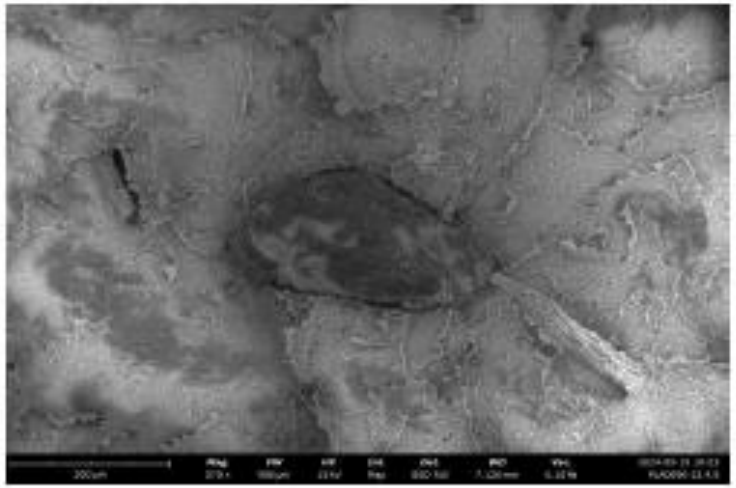
White particle 570 x

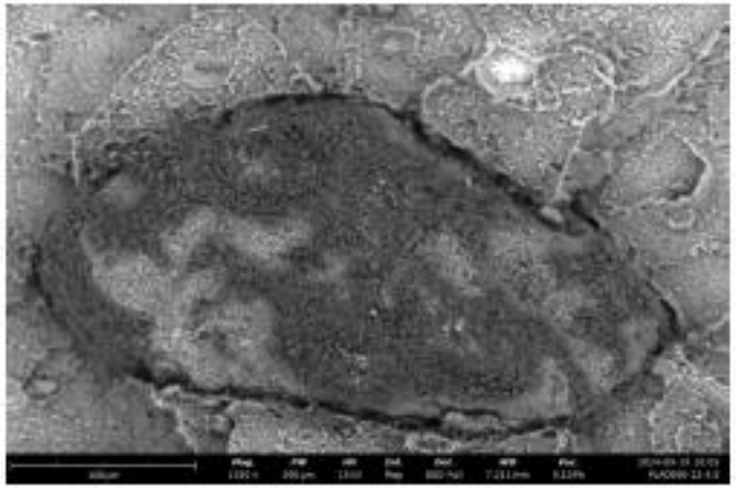


White particle 1350 x

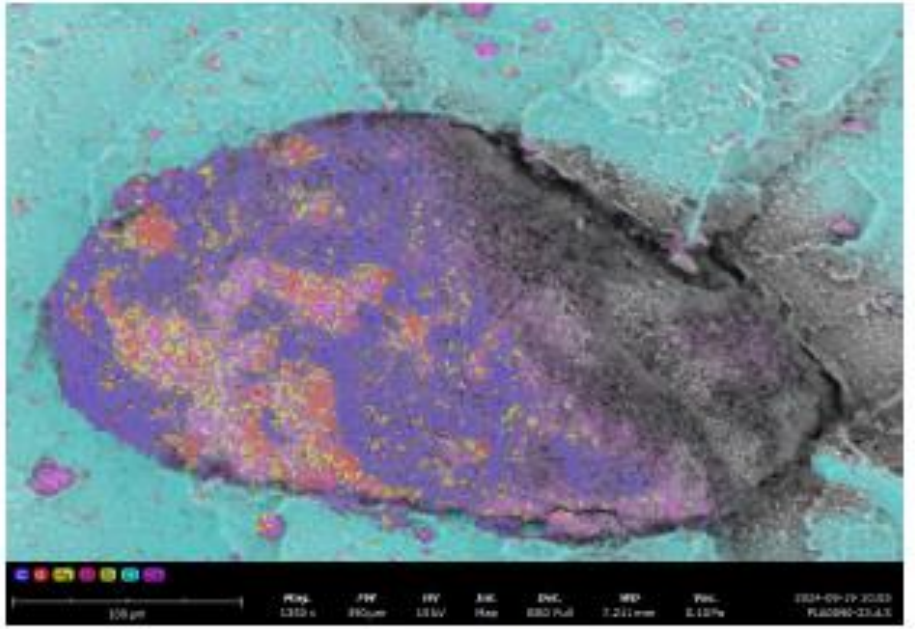
Investigation brittle failure test sample PLA090/23.04.05(4999h)

Partícula Blanca Sin Identificar (330 µm)





Análisis SEM – EDS

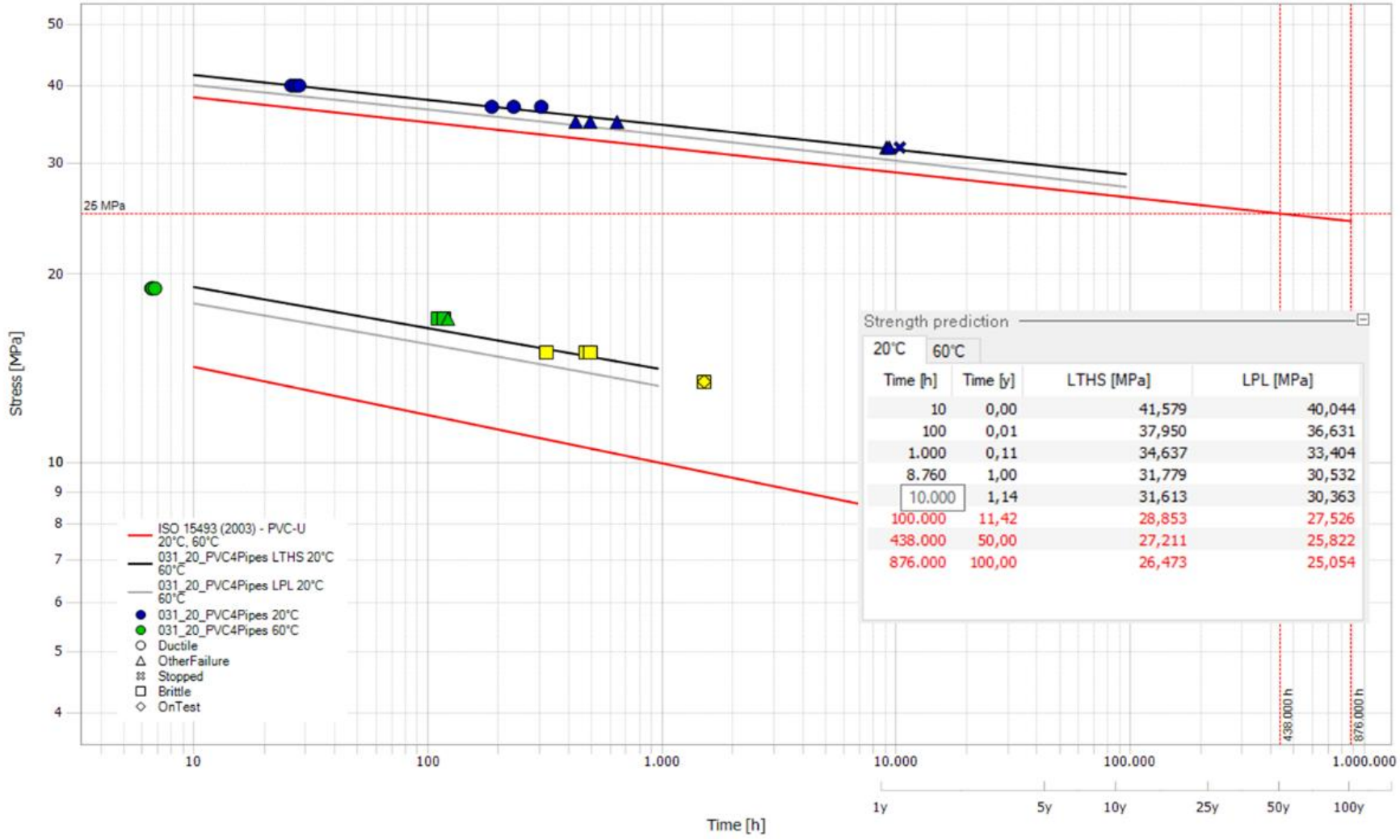


	Element Number	Element Symbol	Element Name	Atomic Conc.	Weight Conc.
	6	C	Carbon	66.808	51.859
	8	O	Oxygen	22.061	22.814
	12	Mg	Magnesium	0.256	0.402
	13	Al	Aluminum	0.692	1.206
	14	Si	Silicon	0.664	1.206
	17	Cl	Chlorine	7.192	16.482
	20	Ca	Calcium	2.328	6.030

Part IV

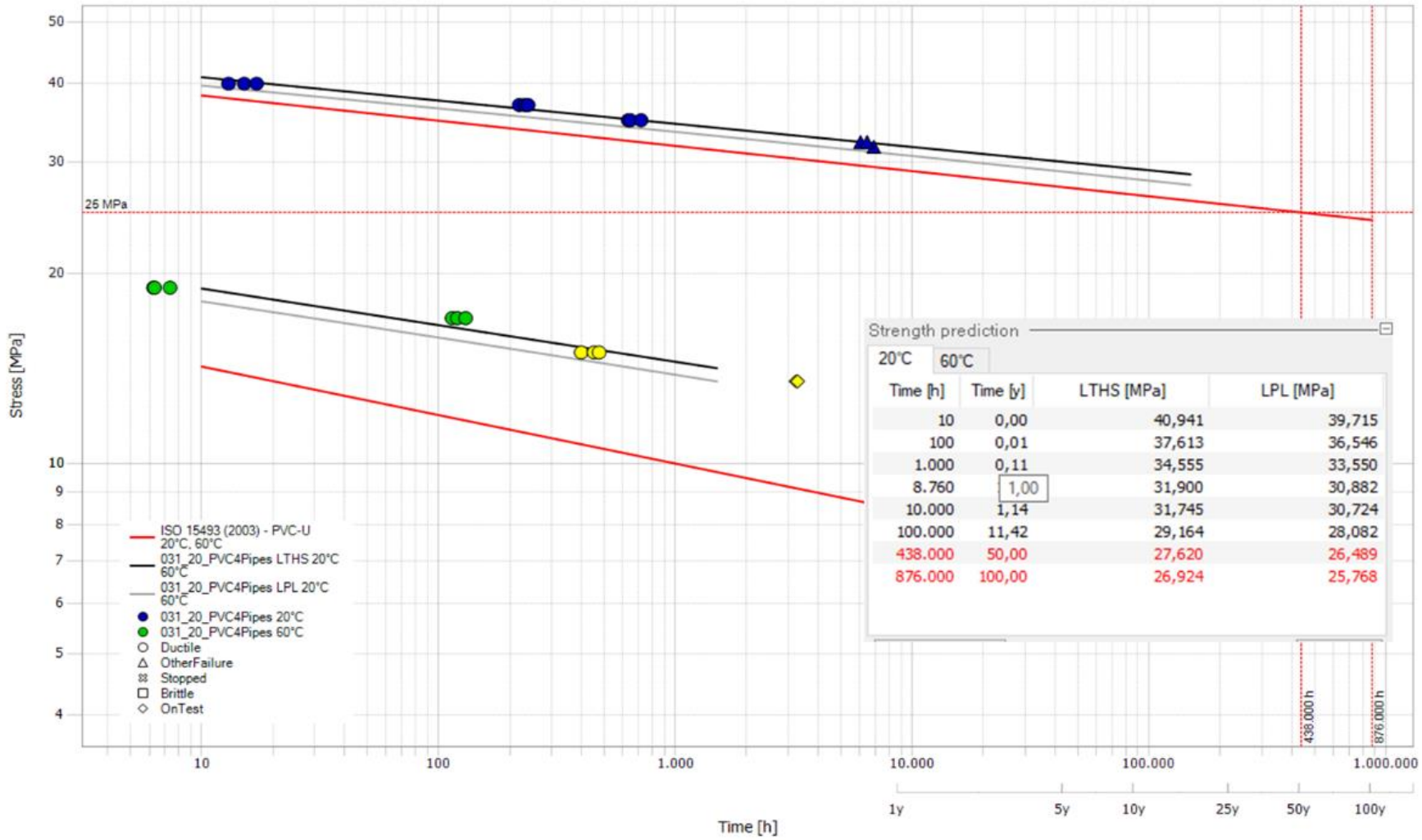
MRS AND $CRS_{20ºC,100y}$ EVALUATION

Reference PLA0031/20.07 (184°C) & PLA0090/23.03b (188°C)



Time [h]	Time [y]	LTHS [MPa]	LPL [MPa]
10	0,00	41,579	40,044
100	0,01	37,950	36,631
1.000	0,11	34,637	33,404
8.760	1,00	31,779	30,532
10.000	1,14	31,613	30,363
100.000	11,42	28,853	27,526
438.000	50,00	27,211	25,822
876.000	100,00	26,473	25,054

Reference PLA0031/20.08 (191ºC) & PLA0090/23.04b (194°C)

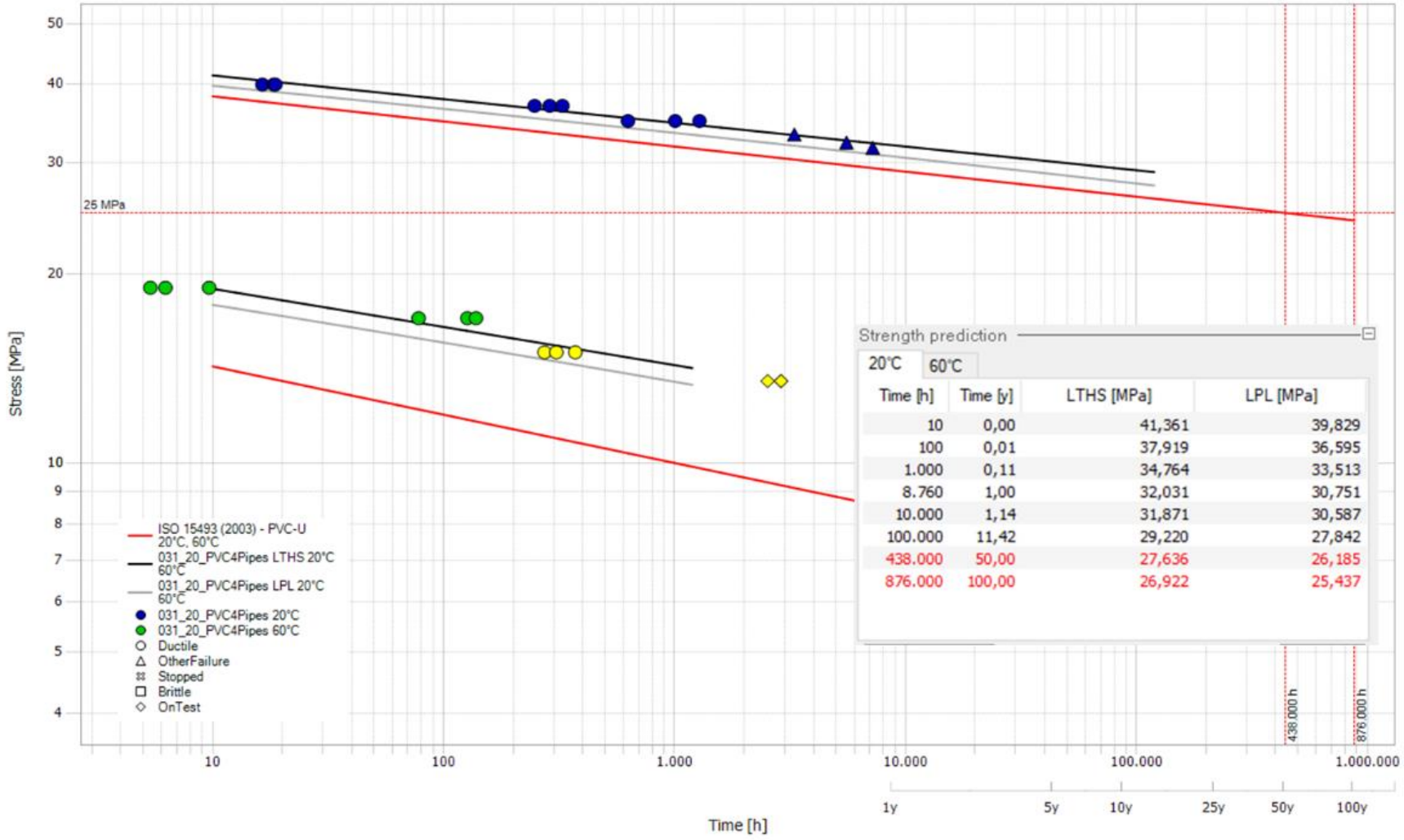


Strength prediction

20°C | 60°C

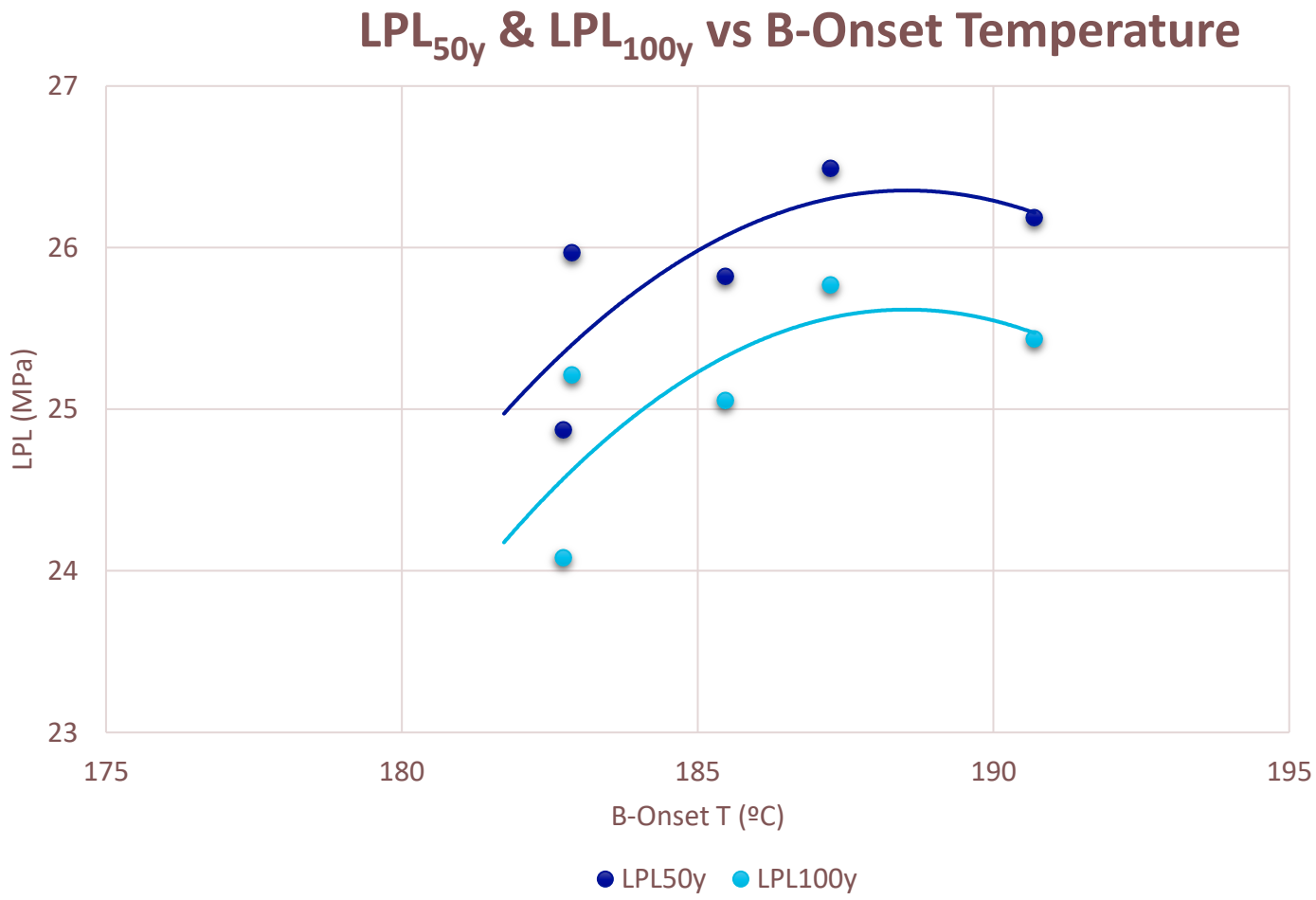
Time [h]	Time [y]	LTHS [MPa]	LPL [MPa]
10	0,00	40,941	39,715
100	0,01	37,613	36,546
1.000	0,11	34,555	33,550
8.760	1,00	31,900	30,882
10.000	1,14	31,745	30,724
100.000	11,42	29,164	28,082
438.000	50,00	27,620	26,489
876.000	100,00	26,924	25,768

Reference PLA0031/20.09 (195ºC) & PLA0090/23.05b (197°C)



Ref. Temp.	PLA0031/20	PLA0090/23	LPL_{50y}	LPL_{100y}
(ºC)	Sample	Sample	(MPa)	(MPa)
185	07 (184°C)	03b (188°C)	25.82	**25.05**
190	08 (191°C)	04b (194°C)	26.49	25.77
195	09 (195°C)	05b (197°C)	26.18	25.44

- The slope of the predicted regression curves drops when melt temperature increases, resulting in higher LPL_{50y} & LPL_{100y} predicted values


LPL50y & LPL100y vs B-Onset Temperature
27
26
25
24
23
LPL (MPa)
175
180
185
190
195
B-Onset T (ºC)
LPL50y
LPL100y

Part V

CONCLUSIONS

- An adequate Ca/Zn stabilised S-PVC K66-68 compound processed a with conical or parallel twin screw extruder with a melt temperature of at least 185ºC, allows to achieve a LPL_{100y} ≥25MPa.
- DSC analysis (B-onset temperature, gelation degree) is a powerful tool for Quality Control of both extrusion and testing conditions.
- While a B-onset temperature of 180°C is required to achieve a MRS 250 classification, a B-onset temperature above or equal to 185°C is needed to achieve a LPL_{100y} prediction above 25 MPa.
- A DSC gelation degree of minimum 70% is needed to achieve a LPL_{100y} prediction of 25 MPa.
- A further increase in the gelation degree above 80%, only leads to marginal gains in LPL's and increases the risk of PVC degradation.

PVC 4 PIPES

Thank you!

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