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PVC-U PIPES: OPTIMAL EXTRUSION CONDITIONS FOR A 100+ YEAR DESIGN LIFETIME

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SHORT SUMMARY

It is well known that the extrusion conditions decisively affect the degree of gelation of PVC-U and through it, the physical characteristics and properties of PVC-U pipes for the transport of pressurized water. The design lifetime of PVC-U pipe will, consequently, also be affected. The choice of optimal extrusion conditions can lead to an extension of the design lifetime to more than 100 years by keeping the initial design stress values and design coefficients unchanged.

KEYWORDS

PVC-U pressure pipes, onset temperature by DSC, Lower Prediction Level, Service Design Lifetime.

ABSTRACT

An investigation project was launched in 2020 to clarify the relationships between the processing conditions and the design lifetime of PVC-U 250 pipes. Ca/Zn stabilized pressure pipes were extruded with different processing temperatures and characterized by their DSC B-onset temperature and degree of gelation. Their long-term hydrostatic strength was predicted using the methods described in ISO 9080:2003. The desired outcome of this project was to set up a correlation between the extrusion temperature and the 97.5% Lower Prediction Level of the stress that a PVC-U pipe can withstand after 100 years (LPL_{100y}).

The results of this study show that an extrusion temperature of 180ºC is high enough to achieve a class MRS250. A moderate increase (+5ºC or +10ºC) of the extrusion temperature leads to a smooth decrease in the slope of the regression curve at 20ºC and, therefore, to an increase of the predicted LPL_{100y} values. Higher processing temperatures (≥195ºC) result in only marginal increases in the Lower Prediction Levels, with clear risk of material degradation during processing.

The increase of LPL_{100y} allows the initial MRS250 classification to be extended up to 100+ years. The resulting benefit for the prescribers and designers of pressurized water supply networks is to design their networks for 100+ years by using of design stress and design coefficient values typically used for a design lifetime of 50 years.

INTRODUCTION

For decades, PVC pipes have helped to provide access to clean water and sanitation all over the world at affordable costs. Being easy to install and highly durable, the PVC pipes have enabled efficient irrigation even in remote areas and have helped to address global issues such as soil erosion and water scarcity. Over the years, it has become evident that the life expectancy of plastic pipe system for the transport of pressurized water made of PVC-U can far exceed the 50-year design lifetime secured by the product standards, by maintaining its original design conditions.(1)

Being part of a comprehensive project, whose objective is to highlight the close relationships between processing temperature, gelation degree and long-term pressure resistance of PVC-U pipes, the present study, focuses on processing conditions that allow them to reach a 100+ year design lifetime.

NOMENCLATURE

DSC	Differential Scanning Calorimetry
LPL	Lower Prediction (stress) Limit
MRS	Minimum Required Strength

EXPERIMENTAL

The pipes were prepared and tested according to the below described process:

1. RAW MATERIALS AND RECIPE MIXING CONDITIONS

The pipe compound used in this study, consists in a mixture of Poly(vinylchloride) (PVC), mineral filler (chalk) and a one-pack Ca/Zn stabilizer package, and includes pigments to achieve desired color (iron grey, RAL7011). 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.

The references of used raw materials and their respective dosage level in p.h.r. (per hundred resin) are depicted in the Table 1.

Component	Reference	Supplier	Dosage level (p.h.r.)
S-PVC (K66-68)	Solvin 267 RC	Ineos Inovyn Ltd.	100
Filler (coated chalk)	Lubricarb 3TS	Minera del Santo Angel S.L.	6.0
Additives (incl. pigment)	Cores SZ 7011	Asua Products S.A.	3.2

Table 1: PVC-U pipe compound composition and dosage level

Solvin 267 RC is a well known extrusion grade homopolymer with a bulk density of 0.58 g/cc and a viscosity index of 67, manufactured in the Ineos Inovyn Ltd.'s site at Martorell, near Barcelona. The filler Lubricarb 3TS is a coated calcium carbonate with a D50 of 2.6µm, obtained from the limestone quarries of Minera del Santo Angel, S.L. near Sevilla. Cores SZ 7011 is a Ca/Zn one-pack stabilizer package including Grey RAL 7011 pigment, developed by the well know Spanish stabilizer Asua Products S.A. in Sondika, near Bilbao.

2. EXTRUSION TEST PARAMETERS

After a storage period longer than 24 h in a silo, the elaborated premix is being fed to a conical twin screw extruder (CM-80-SC, Milacron Inc.), using a gravimetric dosage unit SAVEOMAT 3.12s from iNOEX GmbH. The extruder adaptor is fitted with a pressure and temperature sensor probe located in the melt stream. A standard spider type die head (LC250, extrusion range DN140-250mm) is selected to shape the pipes.

All pipes are extruded to comply with a S12.5 (C=2.0) DN 140x5.4mm PN10 classification, as defined in ISO 1452-2:2009. The extrusion conditions used for the pipes tested in this paper, are detailed in Table A1 of Annex A.

3. EXTRUSION PIPE SAMPLES

For the present project, each extrusion test reference has been identified with their respective melt temperature: 175°, 180°, 185°, 190° and 195°C as measured by the temperature sensor probe. From each extrusion test, four 6-meter long pipe samples have been selected. Each pipe sample has been clearly identified with their test reference number and extrusion melt temperature.

4. MRS EVALUATION: LPL_{50y} & LPL_{100y} PREDICTIONS

The equipment involved in hydrostatic pressure testing includes an IPT 1721-061 pipe tester (range up to 100 bar, ± 2 %), two IPT 1751-1761 liquid baths (range 20°C & 60°C, ± 2°C, respectively) and nine IPT 1732-0140 end-cups sets of DN 140mm from Institut für Prüftechnik Gerätebau GmbH & Co. KG.

A comprehensive pressure test program has been planned in accordance with ISO 1167-1:2006 & ISO 1167-2:2006. Table 2 and Table 3 show the respective pressure testing program at 20°C and 60°C with the rupture times of test specimens. Pressure stresses has been selected to achieve rupture times distributed over at least three decades in time. Two TEPFFA and one ISO 1452-2:2009 control points are included in the testing program.

Pipe Sample	Pressure testing rupture time results (h)			
Ref / °C	20°C/40MPa	20°C/37MPa	20°C/35MPa(a)	20°C/31.87MPa(b)
05/175°C	32.8/33.4/32.7	149/275/283	498/630/656	9388(c)/9388(c)/9102(c)
06/180°C	20.3/22.5/20.4	213/241/312	476/502/524	9388(c)/9388(c)/9216(c)
07/185°C	26.1/27.1/28.1	187/304/232	427/493/642	9093/9328/10359(c)
08/190°C	17.0/13.0/15.1	232/219/239	632/645/716	On test
09/195°C	18.7/16.4/18.4	288/248/227	628/1006/1281	On test

Table 2:
(a) TEPFFA control points; (b) ISO 1452-2:2009 1000h control point; (c) test stopped before rupture

Pipe Sample	Pressure testing rupture time results (h)			
Ref / °C	60°C/19MPa	60°C/17MPa	60°C/15MPa	60°C/11.95MPa(a)
05/175°C	8.8/7.0/6.5	160/135/133	257	1000(c)/1000(c)/1000(c)
06/180°C	6.5/7.7/8.8	89/55/102	665	1000/1000(c)/1000(c)
07/185°C	6.6/6.6/6.8	116/122/110	1257	1000(c)/1000(c)/1000(c)
08/190°C	7.4/6.2/6.3	120/114/131	1499	N/A
09/195°C	6.2/9.7/5.4	78/127/138	1368	N/A

Table 3:
(a) TEPFFA control points; (b) ISO 1452-2:2009 1000h control point; (c) test stopped before rupture

MRS evaluations and LPL_{50y} & LPL_{100y} predictions are performed according to ISO 9080:2003, with the Pipeson© Analyzer licensed software.

5. DSC EVALUATION

A complete Differential Scanning Calorimetry (DSC) analysis has been performed following ISO 18373:2007. Four samples have been taken at 0°, 90°, 180° and 270° positions around the pipe circumference. Thin disks obtained by a hole punch of 20±10 mg are prepared. Each disk is encapsulated in an aluminum pan with perforated & crimped cover to reduce sample movements while melting.

DSC analyses have been carried out in a Perkin Elmer DSC4000 instrument with analysis software Pyris V.10.1.0.0412. Temperature scans runs from 35°C to 240°C at 20°C/min heating speed and N_2 purge gas flow @ 23ºC. The processing temperatures of the pipes were determined by measuring the B-Onset temperatures as described in ISO 18373-2:2007. Gelation degrees were determined as described in reference 1.

RESULTS AND DISCUSSION

The graphical extrapolation obtained for each reference evaluated, are plotted in log(σ) vs log(t) graphs generated with the Pipeson© Analyzer software. The tables embedded in Figures 1 to 5, show the LPL_{50y} & LPL_{100y} predicted values at 20°C for their respective reference.

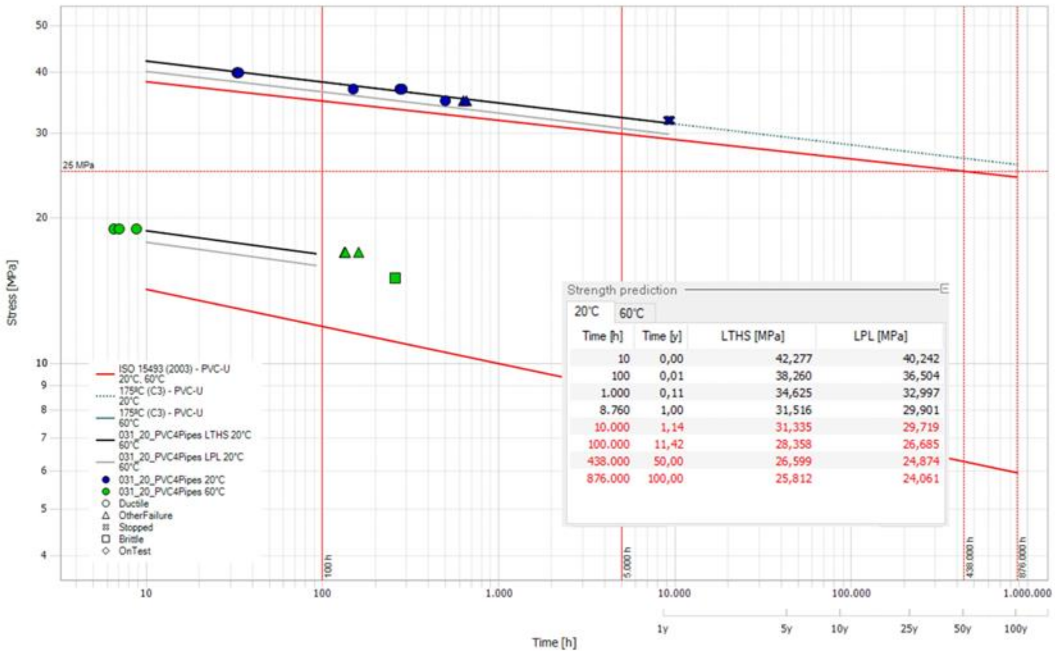

Figure 1: Reference 05/175°C

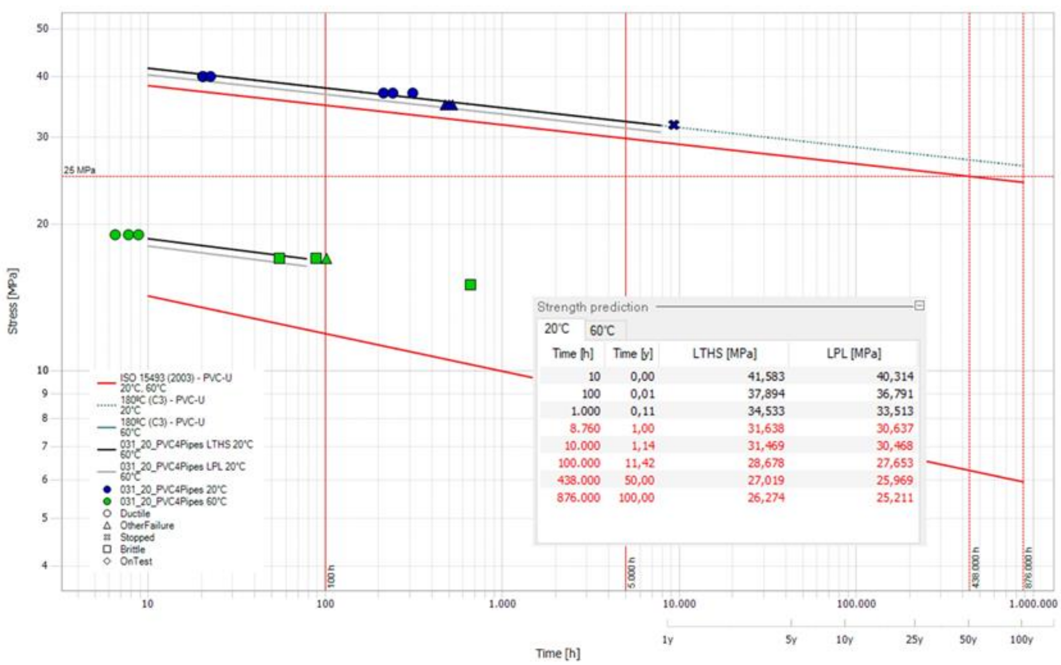

Figure 2: Reference 06/180°C

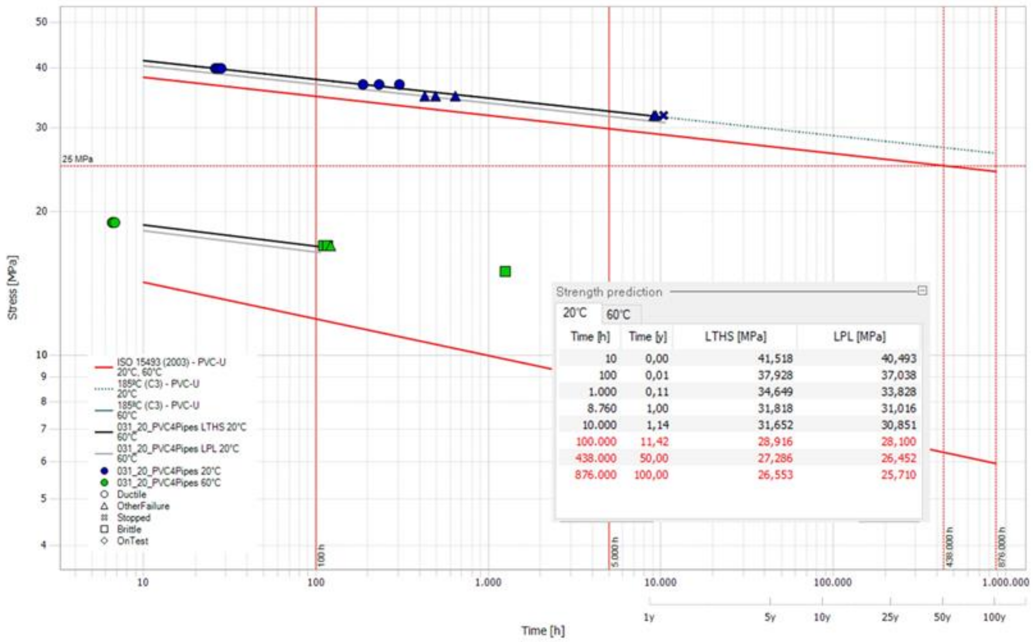

Figure 3: Reference 07/185°C

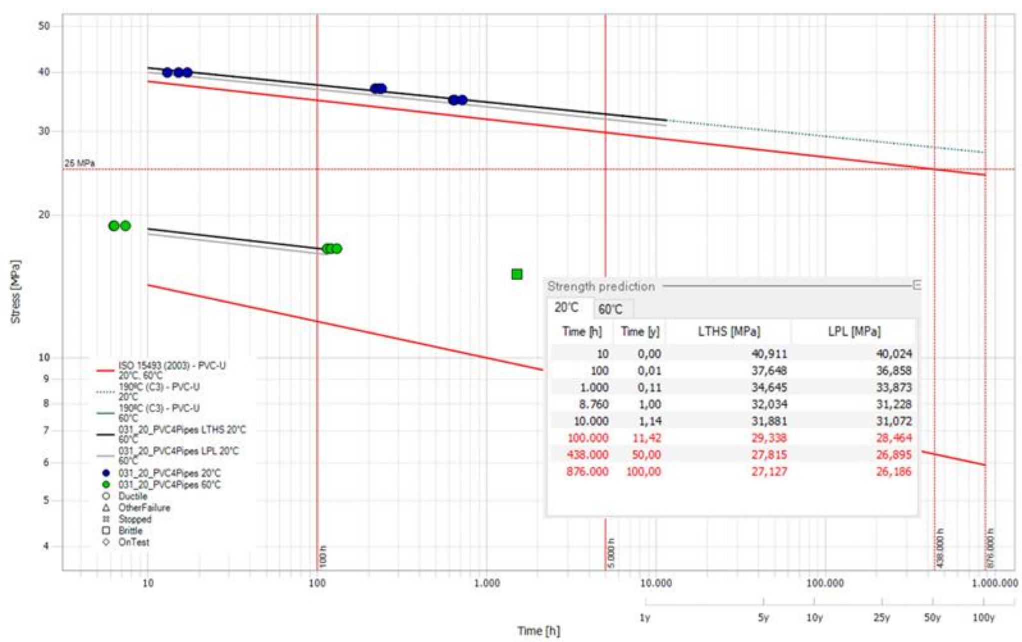

Figure 4: Reference 08/190°C

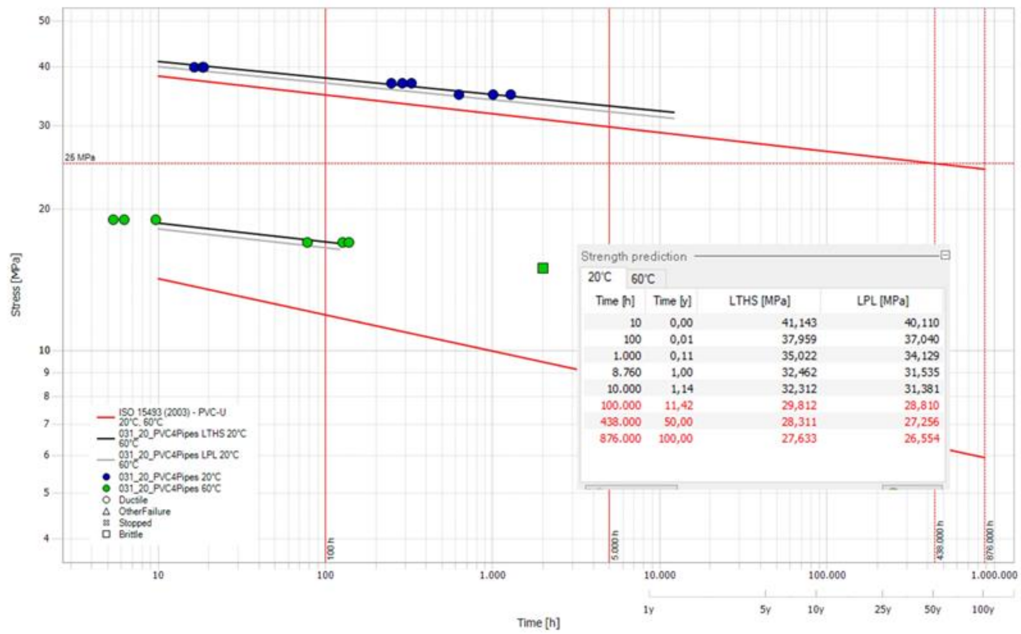

Figure 5: Reference 09/195°C

Rupture times for all specimens exceed TEPPFA and ISO1452-2:2009 control points in, at least, one decade. The slope of the predicted regression curves drops when melt temperature increases resulting in higher LPL_{50y} & LPL_{100y} predicted values as clearly shown in Figure 6.

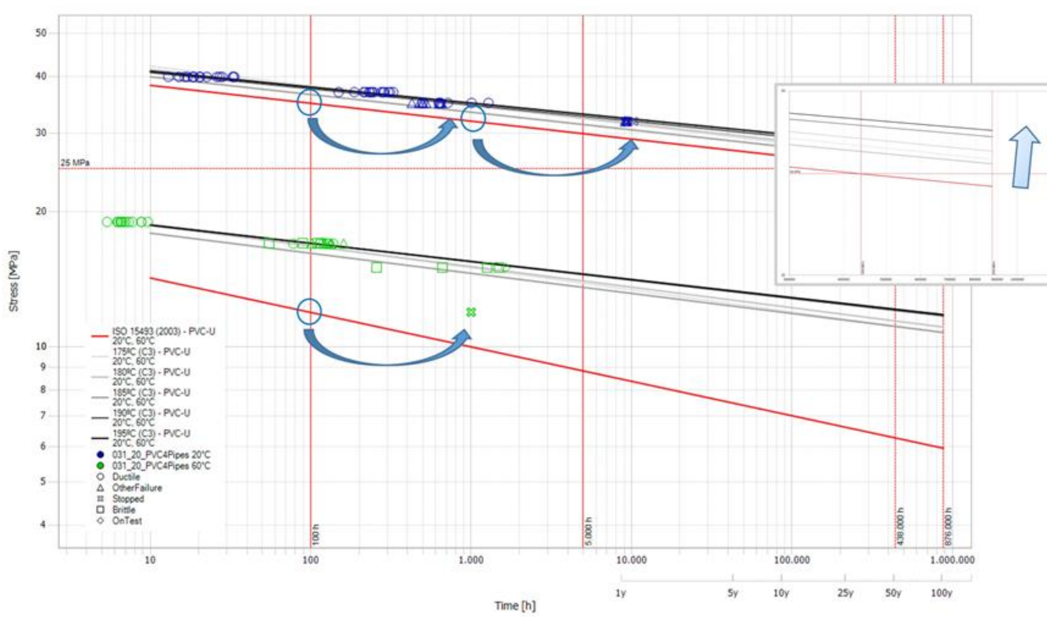

Figure 6: References 05/175°C, 06/180°C, 07/185°C, 08/190°C & 09/195°C

Even if none of the rupture points are below PVC-U reference curve (continuous red lines), the LPL_{50y} of reference 05/175°C is below 25 MPa; an MRS 250 classification cannot be granted. LPL_{50y} and LPL_{100y} for reference 06/180°C are both higher than 25 MPa; a MRS 250 classification could be achieved. As melt temperature increases, higher strength predictions could be achieved, for instance, reference 09/195°C reach 27 MPa and 26 MPa, respectively, for their LPL_{50y} & LPL_{100y} predictions.

The pressure resistance of PVC-U pipes is well known to be related with gelation degree achieved during extrusion process.(3) As described elsewhere,(4) a strong relationship between the predicted LPL's and the gelation degree measured by DSC, following ISO 18373-1:2007 (Figure 7). A gelation degree higher than 70% is needed to achieve a LPL_{100y} of 25 MPa. Further increases in gelation degree beyond 80%, only lead to marginal gains in LPL's.

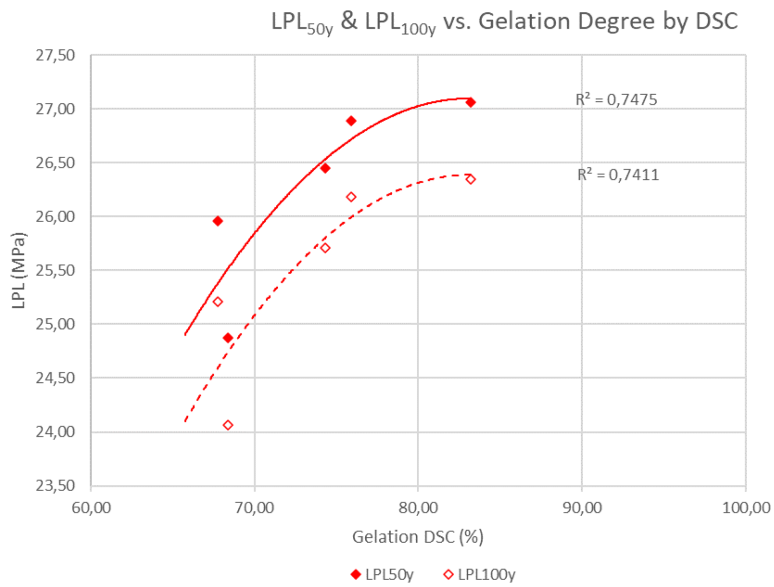

Figure 7: LPL vs gelation degree by DSC

It has also been shown possible to correlate the B-onset temperature with the mass temperature of the melt at the extruder/die head adaptor, despite an offset related to the type of temperature probe used that should be adjusted for each recipe/extruder/probe.

The above correlation could also be evidenced between the LPL's and B-onset temperatures. Estimated LPL_{50y} increases from 25 MPa up to 27 MPa with B-onset temperature because a decrease in the slope of regression curve. B-onset temperature higher than 180°C is required to achieve a MRS 250 classification. Achieving an estimated LPL_{100y} above 25 MPa requires a B-onset temperature of at least of 185°C. Only marginal gains on LPL_{50y} & LPL_{100y} are obtained when increasing onset temperatures to and above 190°C.(4)

CONCLUSIONS

Pressure test rupture times for PVC-U pipes extruded at different temperatures, have been evaluated according to ISO 9080:2003 with Pipeson© Analyzer software and the estimated Lower Prediction Limits (LPL) have been correlated with both DSC gelation degree and B-onset temperature.

A B-onset temperature of at least 180°C is required to achieve a MRS 250 classification. Achieving an estimated LPL_{100y} above 25 MPa requires a B-onset temperature of at least of 185°C. DSC gelation degree of 70% is the minimum needed to achieve a LPL_{100y} estimation of 25 MPa. Further increases in gelation degree beyond 80%, only lead to marginal gains in LPL's.

Ongoing long-term pressure test will help us to make more accurate predictions of the currently available LPL_{100y} estimations. A future paper will disclose regression curve results obtained.

ACKNOWLEDGMENTS

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ANNEX A

TABLE A1

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	06	07	08	09
Dosing screw speed	rpm	18.61	21.08	23.49	26.45	29.16
Screw speed	rpm	8.08	8.08	9.00	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
Tmelt	°C	174/6	180/1	184	190/1	194/5
Pmelt	bar	178/9	203	189	199/202	189
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	2.310	2.298	2.334	2.322	2.322
Output	kg/h	112.8	128.0	141.8	159.3	174.6
Line speed	m/min	0.81	0.93	1.01	1.14	1.25

