Dow Plastics Additives

Enhanced Orientation of PVC Pipe Using Acrylic Processing Aids

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Agenda

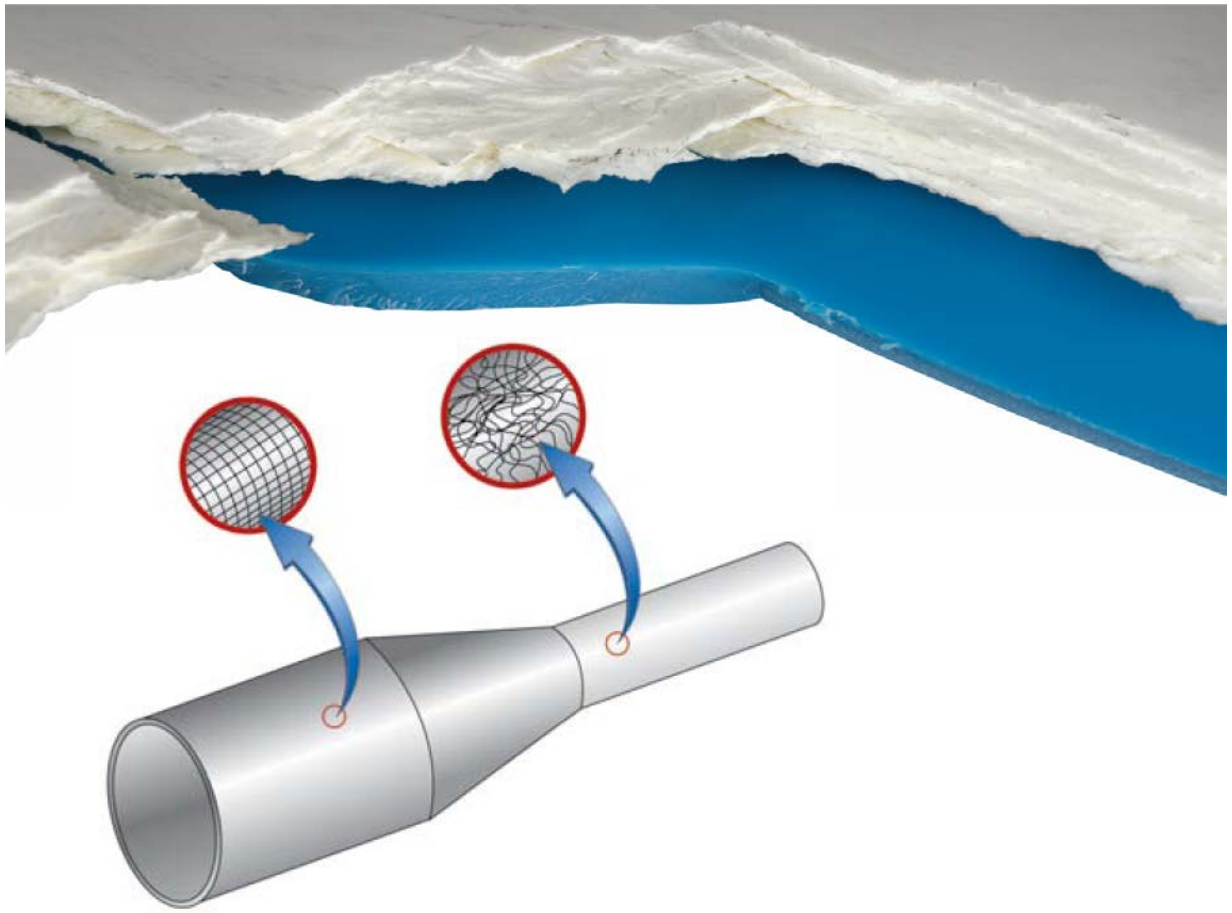
Background
- PVC-O Technology
- PVC-O Market Review

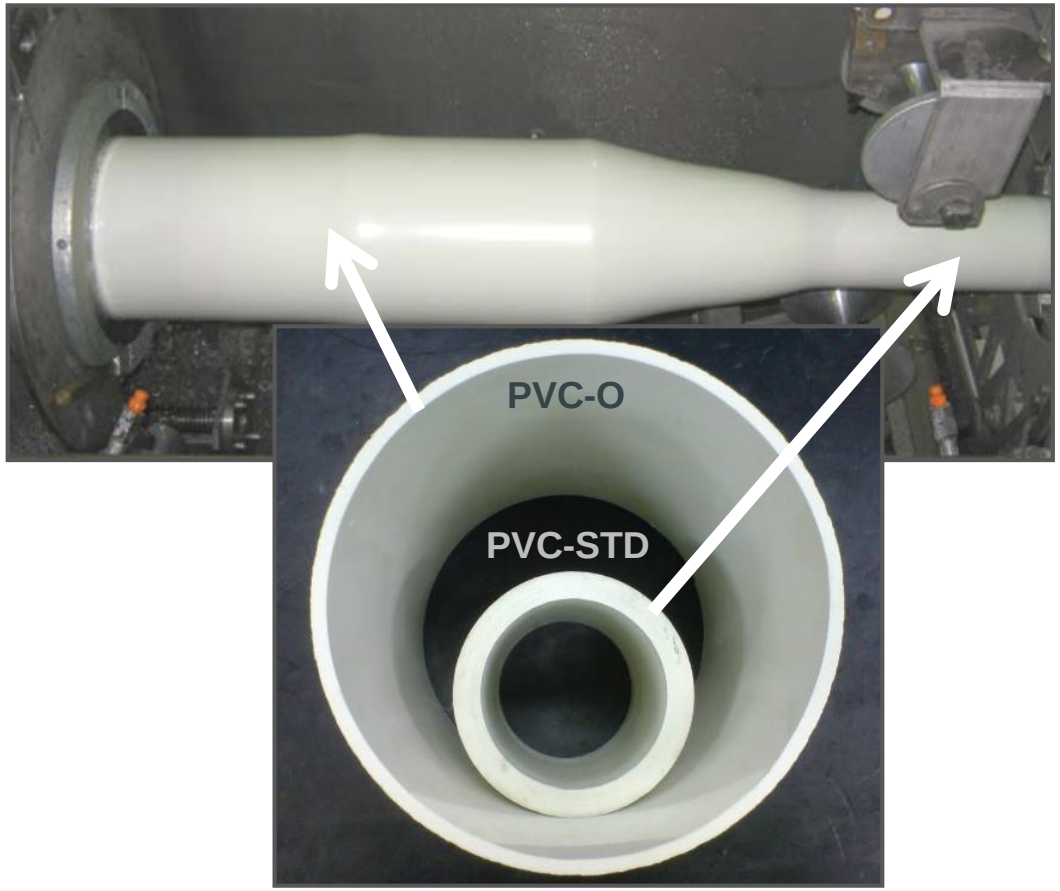
Fundamental PVC-O Material Properties
- Tensile Testing
- Effect of temperature and speed on orientation
- PVC-O in-house capabilities

Acrylic Process Aids
- Melt strength
- Melt Processing

Summary

Oriented PVC (PVC-O) Technology

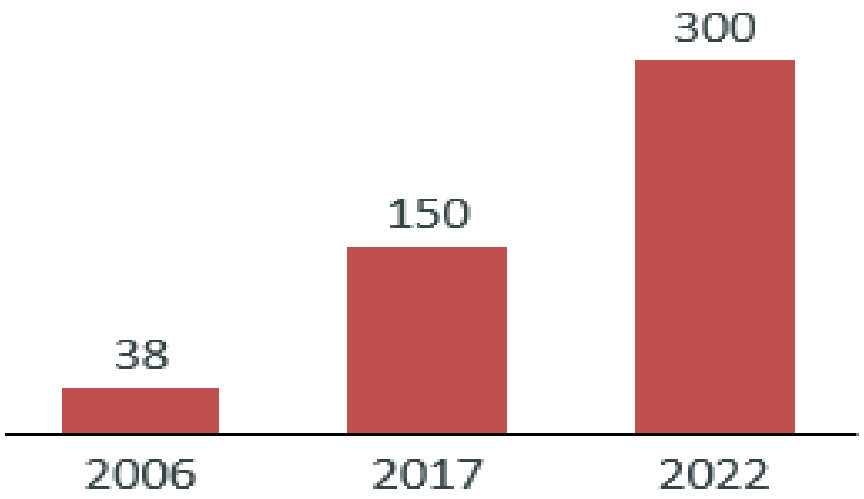




Picture courtesy of PVC-O molecular orientation, Molecore

PVC-O Market Opportunity

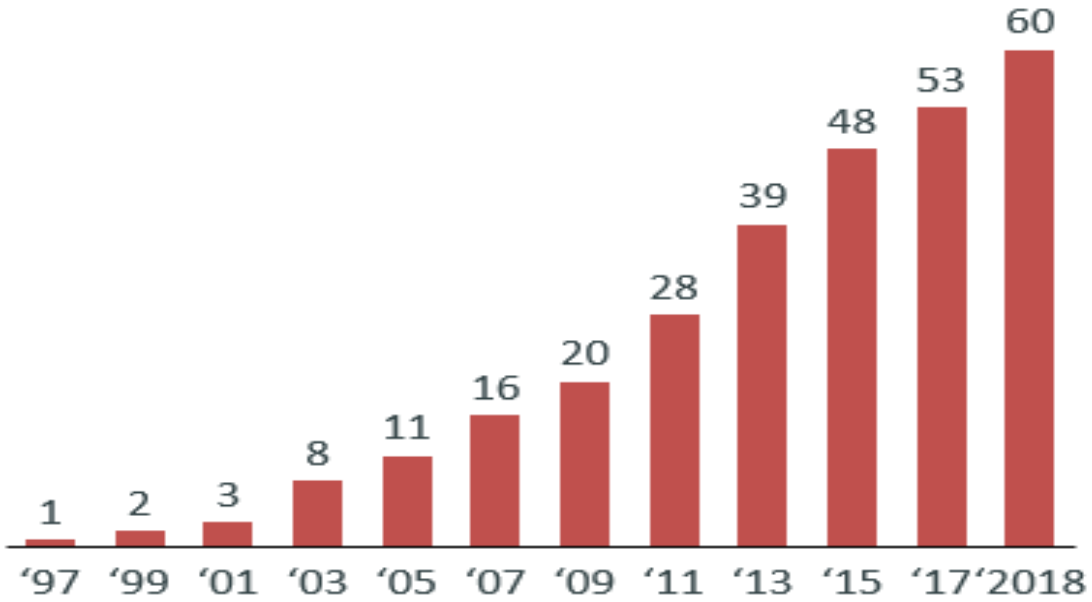
Estimate of PVC-O installed capacity growth (kT) 2017-2022 (1)



2022 global installed PVC-O capacity projections

5 Year CAGR of 14% (’17-22)

Global number of PVC-O lines (2)



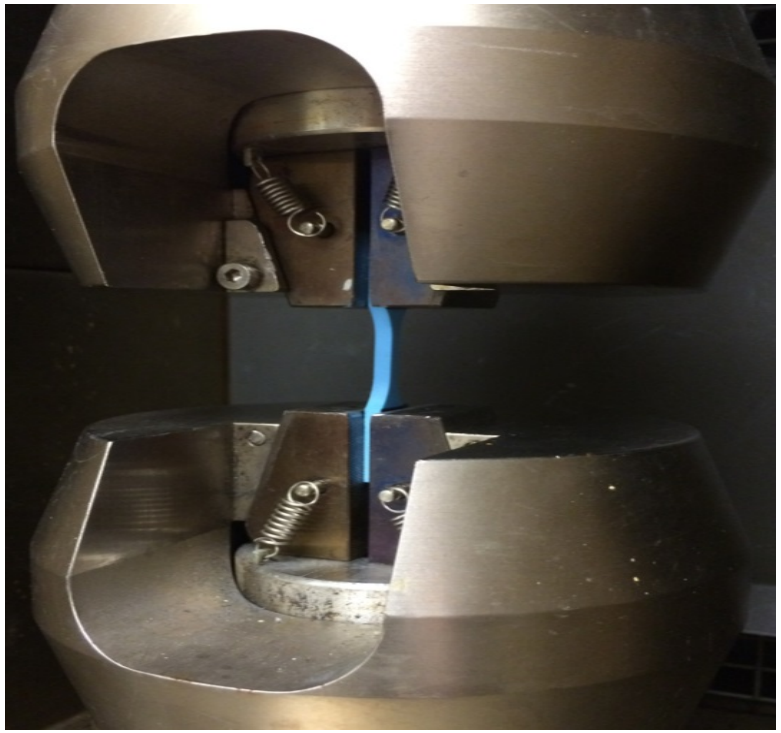
60 PVCO lines globally
(# of lines tripled since ’08)

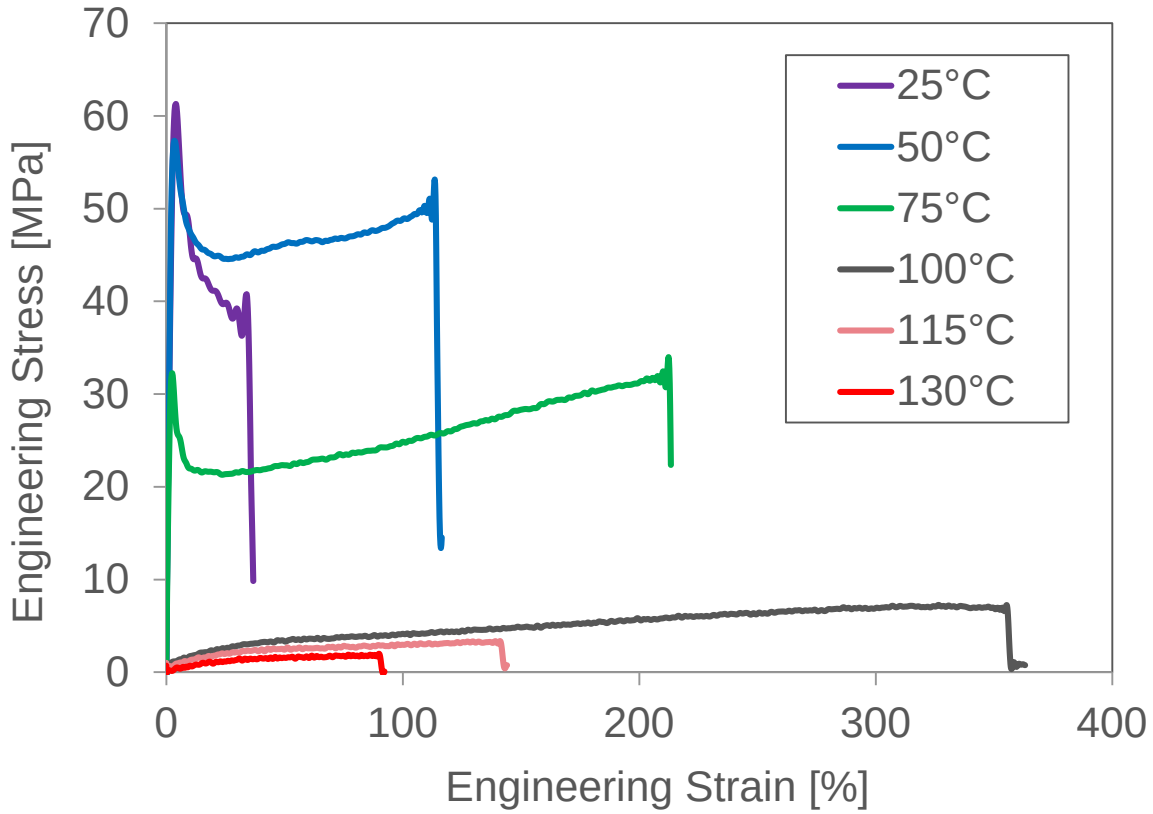
Prior 10 year CAGR of 13% (’08-’18)

1. Molecor published estimate from Pipes and Profile Extrusion Magazine Oct. 2018
2. Andre Nijland (Wavin) Pipes in Infrastructure Conference, London April 2018

Learning from Material Test: Tensile Property

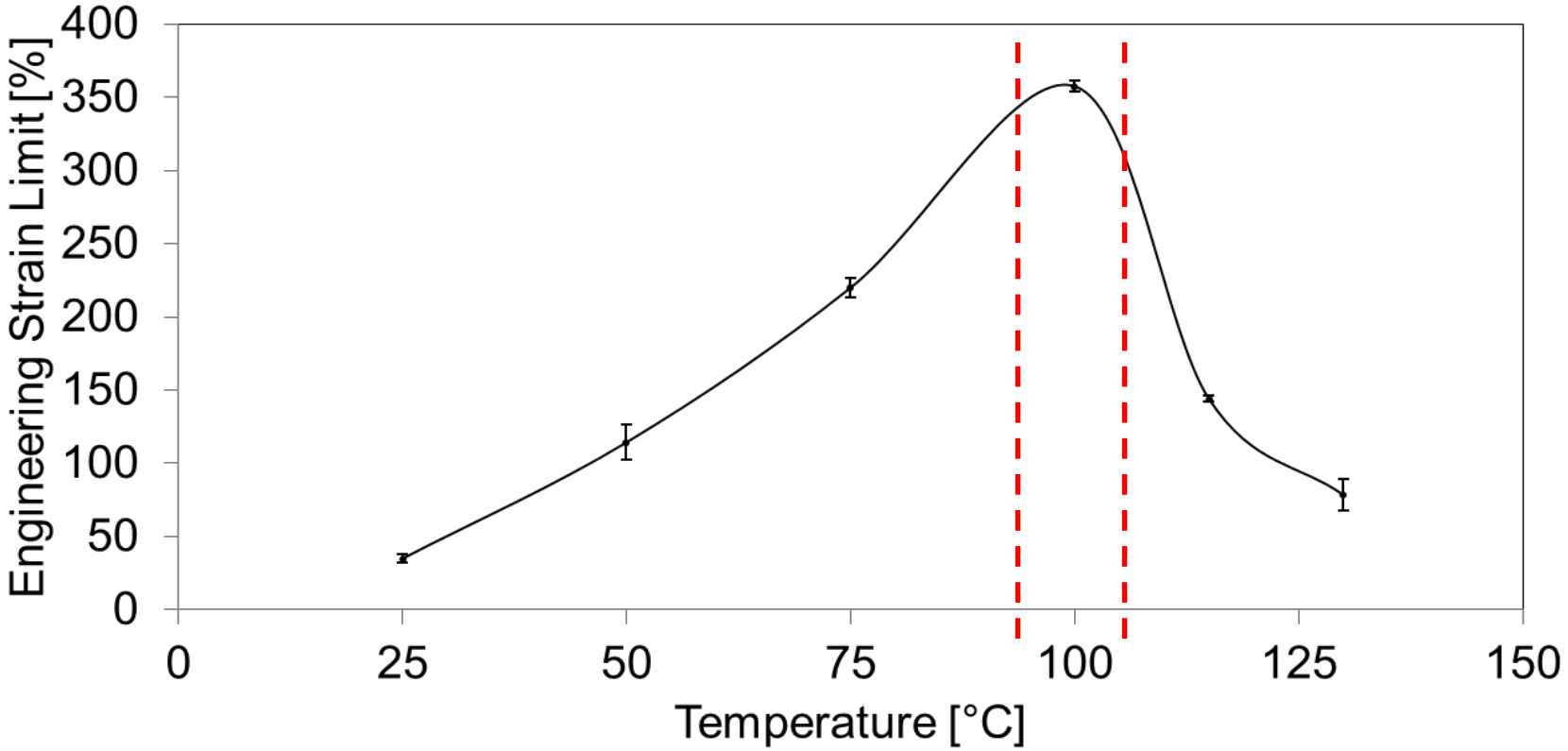
- To understand the temperature effect on the PVC-O process, extruded PVC material property is evaluated at different temperature
- As temperature increases, PVC changes from elastic plastic to hyperelastic material behavior



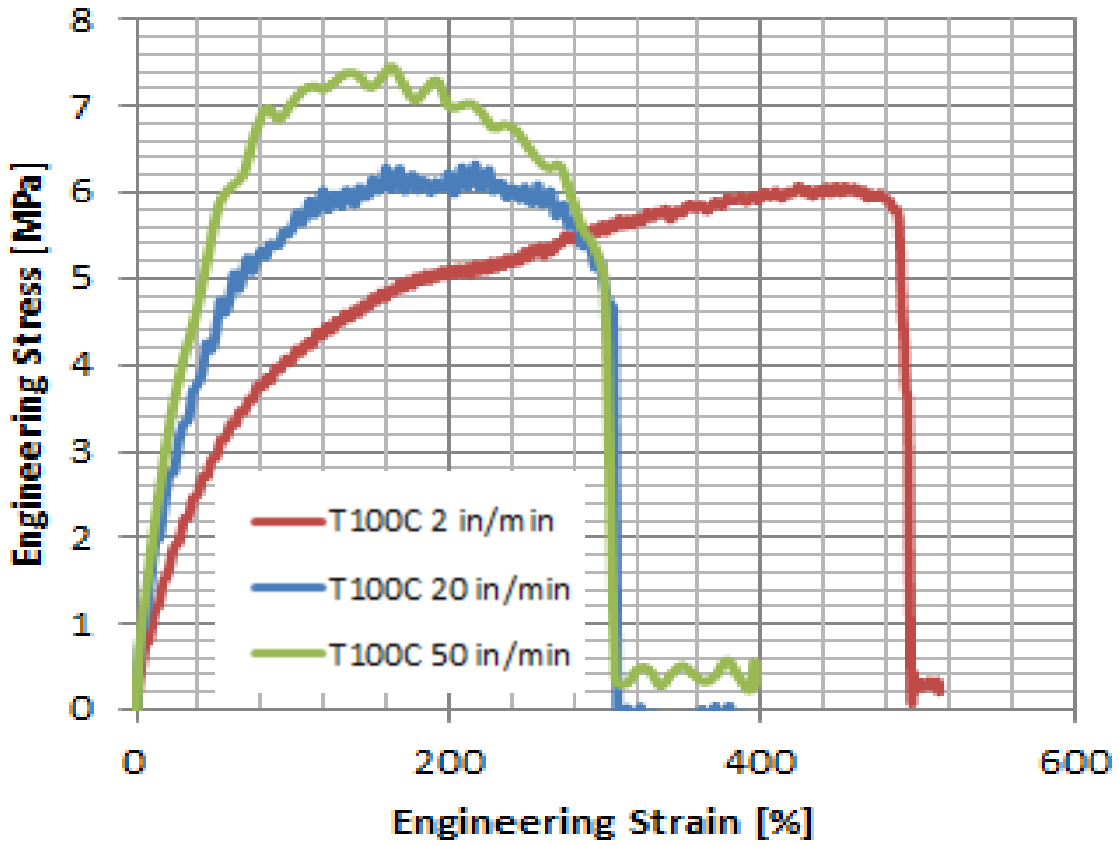


Effect of Temperature on PVC Tensile Strain Limit

- For the PVC-O process, it is better to maintain the temperature where material can achieve highest strain and relatively lower modulus



Tensile Testing: Effect of Pulling Rate



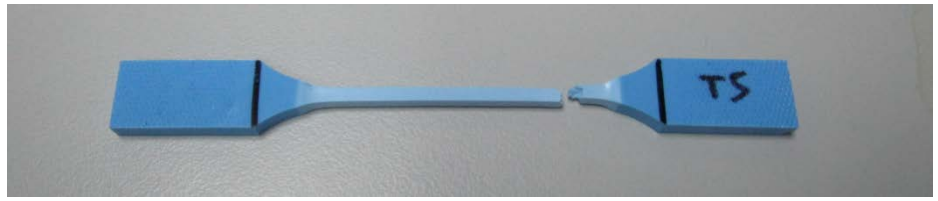
Base PVC-O Formulation:

- Modulus increases with increasing expansion rate
- Max strain decreases
- Failure in hoop expansion predicted at increased expansion rate

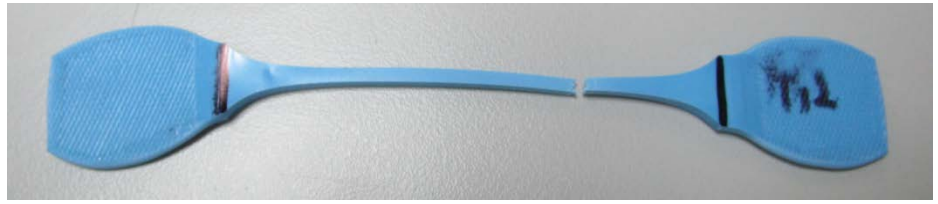
PVC Tensile Testing

Pulling Speed: 2 in/min

T=50 ° C



T=100 ° C



T=130 ° C

Effect of Temperature

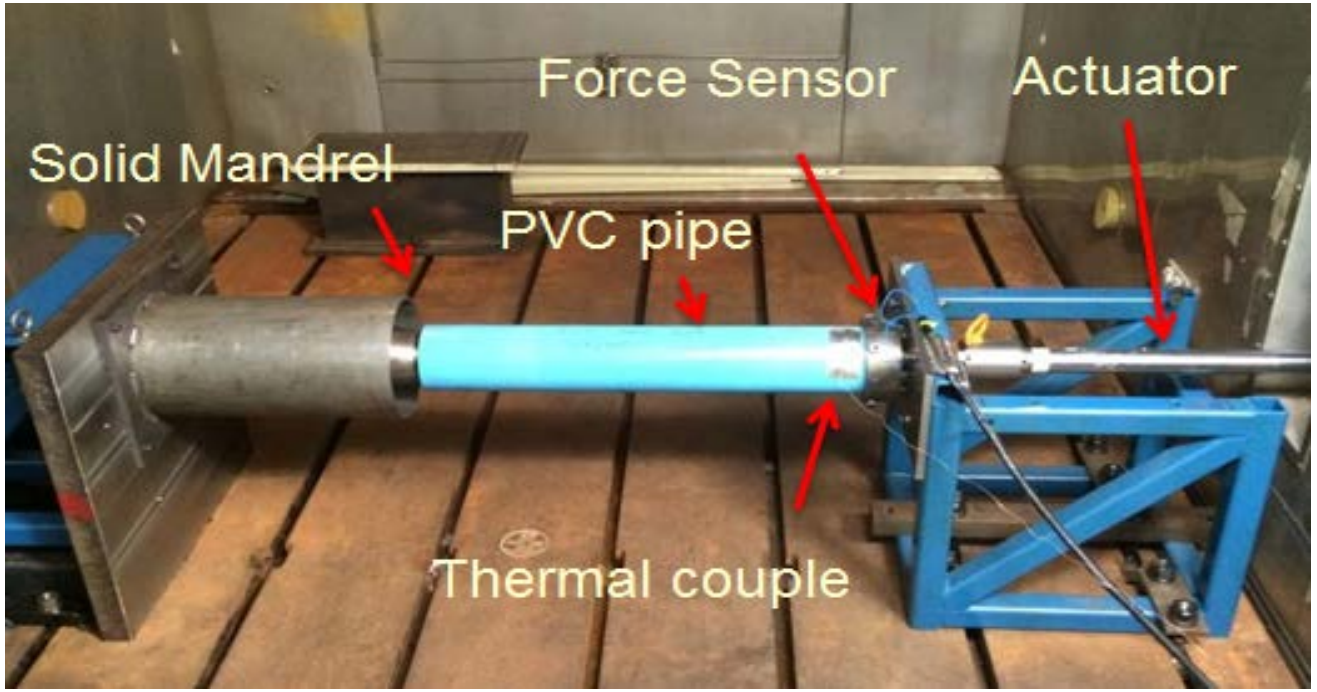
2 in/min

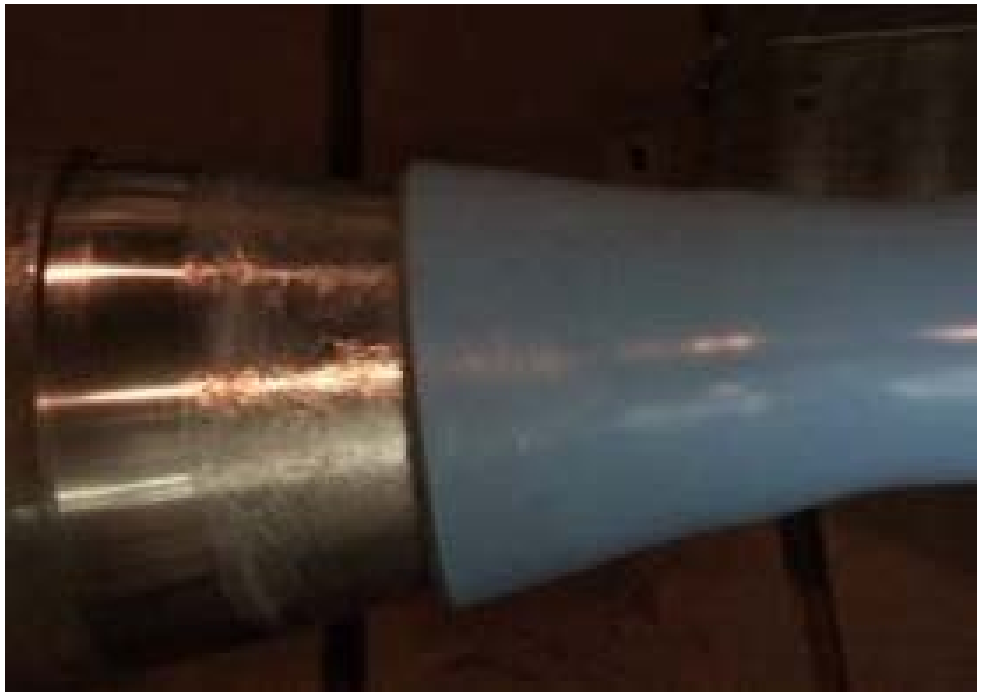
20 in/min

T=100 ° C

Effect of Pulling Speed

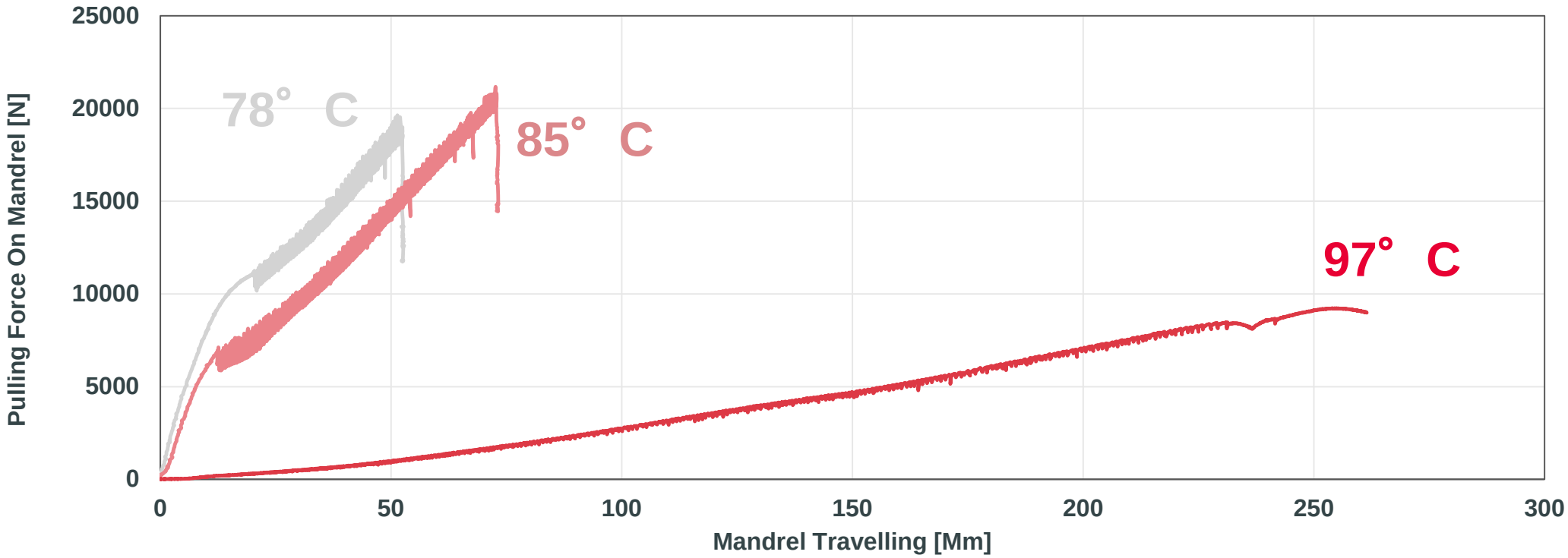
In-house Lab Scale PVC-O Set-up





- Pre-extruded pipe is tested for the PVC-O process by a solid mandrel
- Temperature, pipe expansion and lubrication is controlled in this test
- Expansion force is measured during the PVC-O expansion process

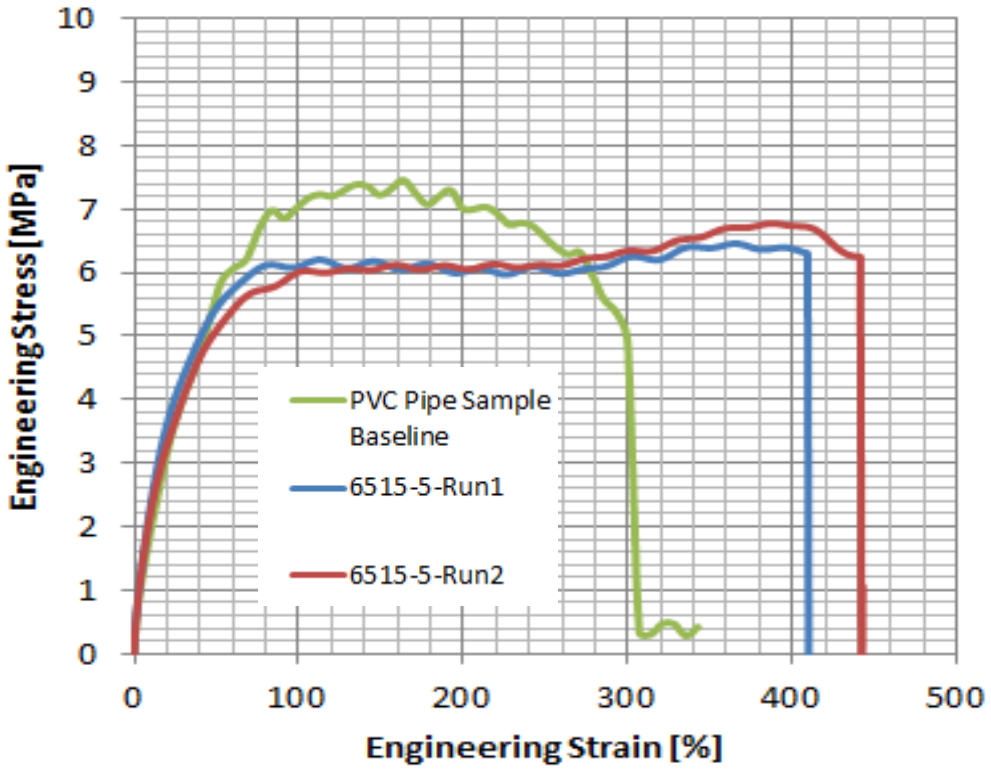
Pulling Force on Mandrel



- As indicated from material test, force measurement from tensile test confirms that Temperature has a significant effect on the pipe expansion
- A few degree temperature drop can lead to significant force increase

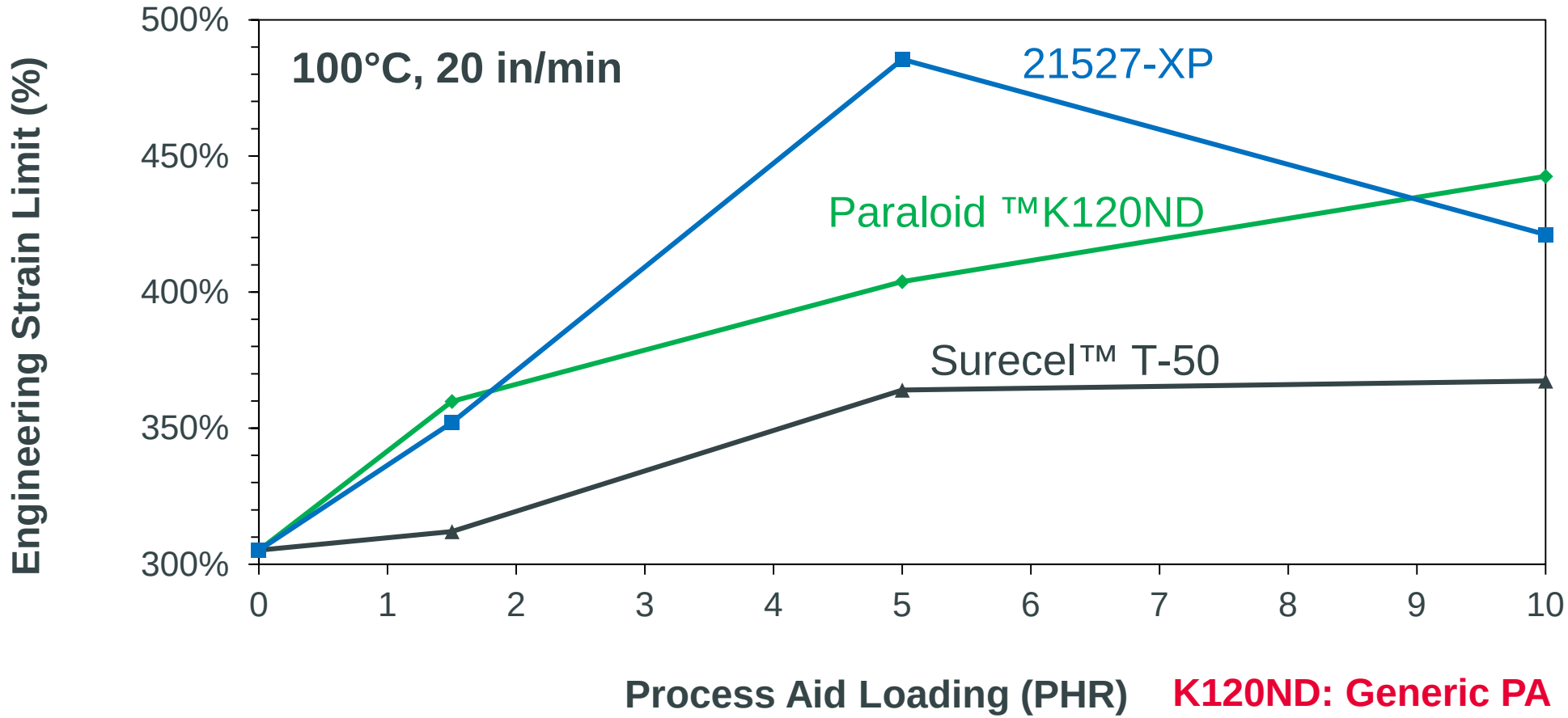
Improved Material Properties: Effect of Processing Aids

100° C and 50 in/min



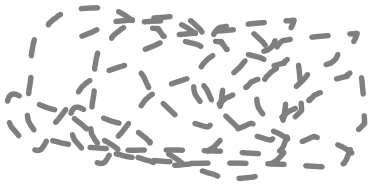
- PVC pipe compound baseline fails at 300%
- New Dow Processing Aid at 5phr 21527-XP (6515-5) shows higher strain limit

Improved Material Properties: Effect of Processing Aid (PA)

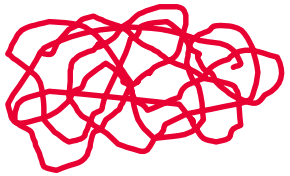


K120ND: Generic PA
21527-XP: PVC-O PA
T-50: Reactive PA

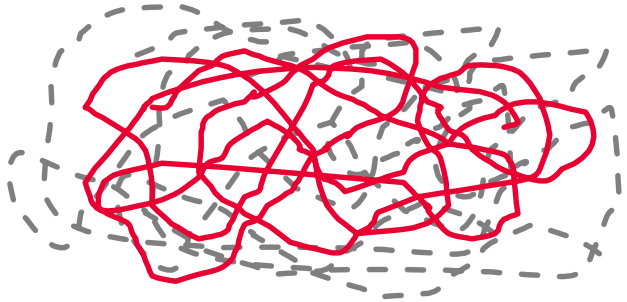
How Acrylic Processing Aid Works?



PVC
Short stiff chains
Low molecular weight



Acrylic Processing Aid
Long flexible chains
Ultra high molecular weight



PVC chains entangled with processing aid chains

- MMA-rich, acrylic copolymers with Mw typically >1MM
- Highly compatible with PVC
- Promotes fusion / gelation of rigid PVC
- Without PAs, rigid PVC fusion and melting can be VERY slow under typical processing conditions

- Enhances melt strength and rheology, enabled by their high compatibility, flexibility and Mw, orders of magnitude greater than the PVC
- Rheology control has become the primary function of PA, driving exact selection and usage level

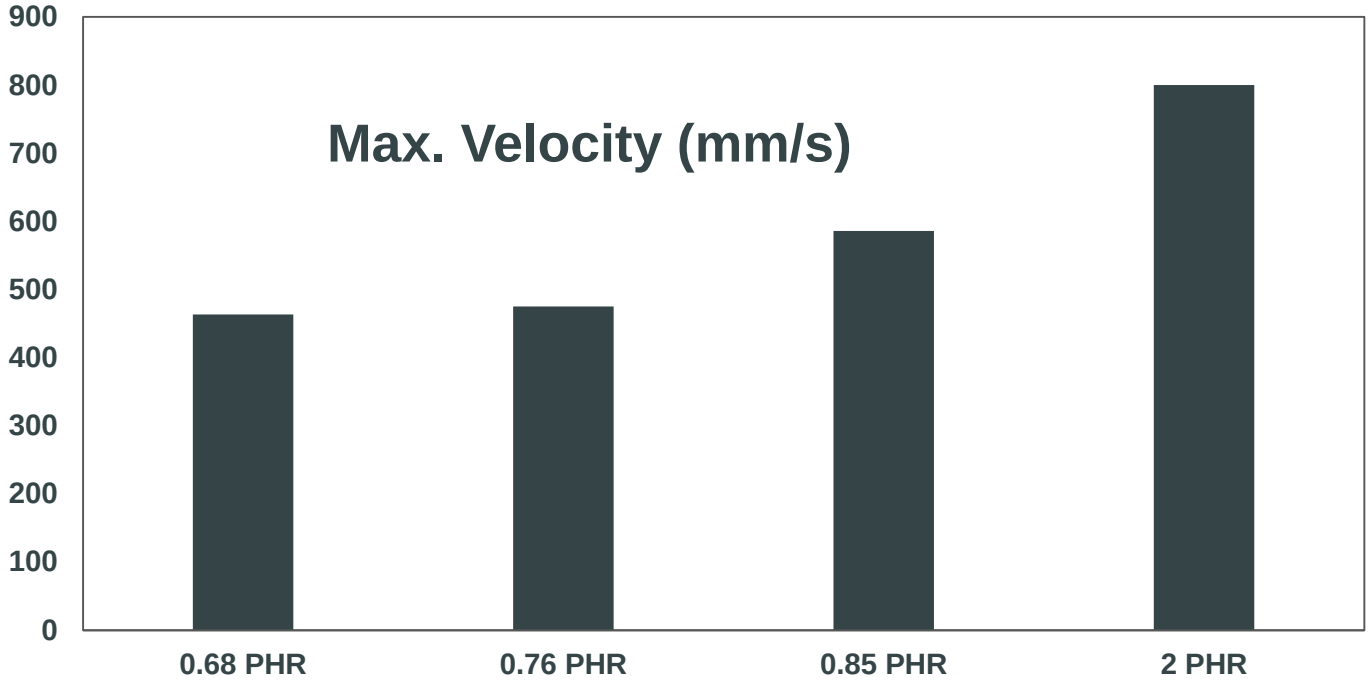
No Effect on Color and Clarity

Haake Rheocord: Melt Strength Evaluation

Haake Rheocord	Screw Speed:	10 RPM	Feeder Speed:	10 RPM
Melt Strength Tester	Height:	75 mm	Gap:	0.6 mm

Haake Extruder	Zone 1	Zone 2	Zone 3	AD	Die
Temperature (° C)	150	155	165	170	170

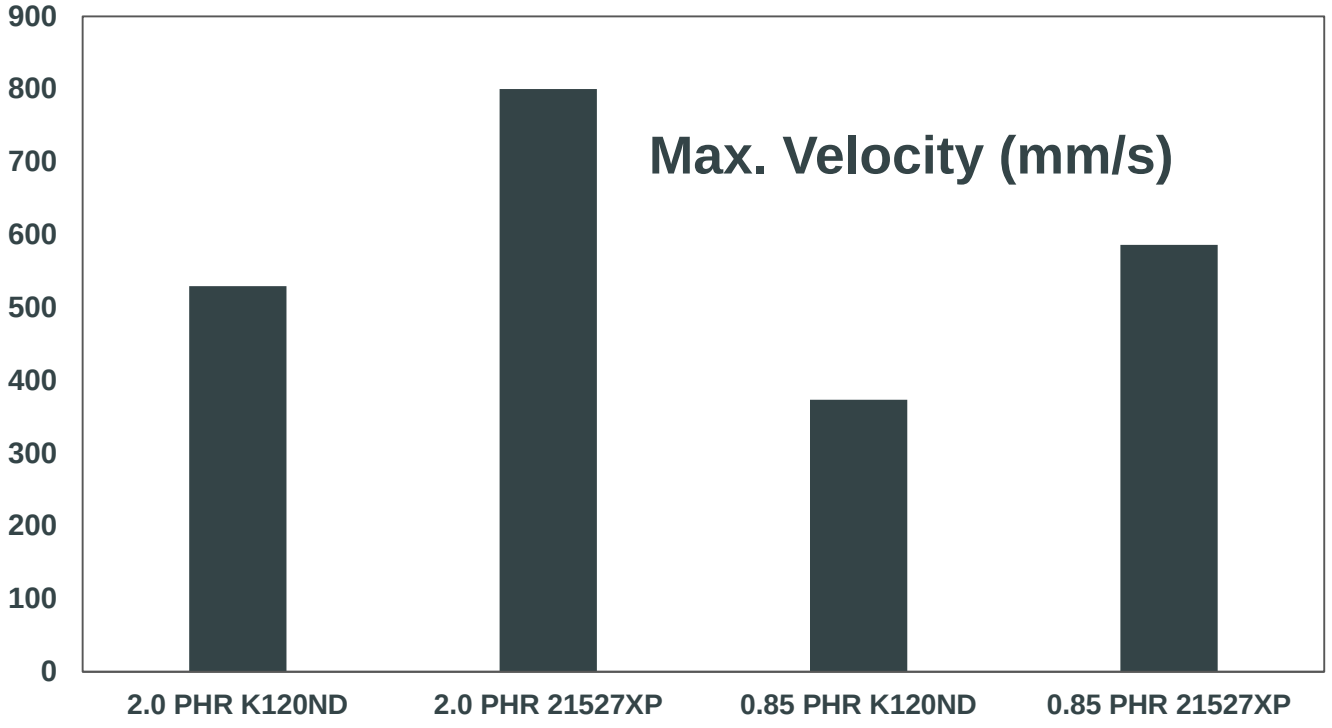
Processing Aid Loading Level



Sample ID	Torque	Z 3	die	Z 3	Die
21527-XP (phr.)	(m*g)	(PSI)	(PSI)	(^{o}C)	(^{o}C)
0.68	2622	1094	837	170	181
0.77	2702	1146	866	170	182
0.85	2800	1175	901	170	181
2.00	3060	1292	982	170	182

- Higher level of processing aid increase melt strength, however, its critical to monitor torques and pressures in extruder and die

Choosing Right Processing Aid



	K120ND 2 PHR	21527-XP 2 PHR	K120ND 0.85 PHR	21527-XP 0.85 PHR
Torque (m*g)	2807	2800	2760	3060
Barrel Pressure (PSI)	1140	1175	1108	1292
Die Pressure (PSI)	834	901	843	982

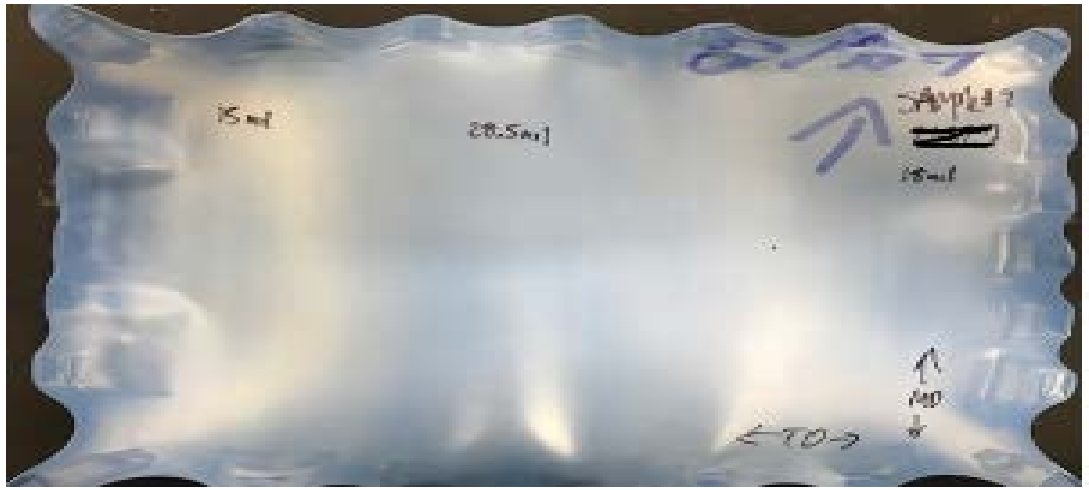
- 21527-XPgives higher melt strength at lower loading level

In-house Biaxial Orientation

Orientation	Biaxial
Heat Soak Time (Min)	8
Temperature (˚ C)	100
Distance TD	3X
Distance MD	2X

2X increase in rate

35 to 70 mm/s in TD and MD



21527-XP

Generic PA

- 21527-XP sustained increased (doubled) orientation speed

Summary

- PVC-O process was evaluated from material perspective
- Maximum elongation was achieved at lower pulling rate
- Optimum temperature (100˚ C) is critical to get maximum orientation
- Higher elongation was achieved by addition of acrylic process aid (PA)
- 21527-XP improved biaxial orientation as demonstrated by tentering frame data
- Improved melt strength was attributed to specifically designed 21527-XP
- Right acrylic PA can improve PVC-O process and productivity