Bridging the gap between Recycled and Virgin Nylon

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Wellman Advanced Materials

01 Carpet Based PCR Nylon Nature

Why is Ecolon differentiated from others ?

PRET WELLMAN

ECOLON

Typical PCR, PIR

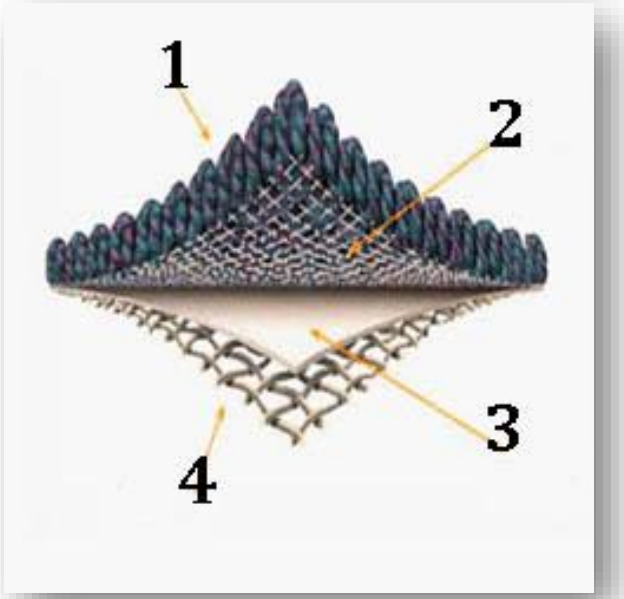
Why is Ecolon differentiated from others ?

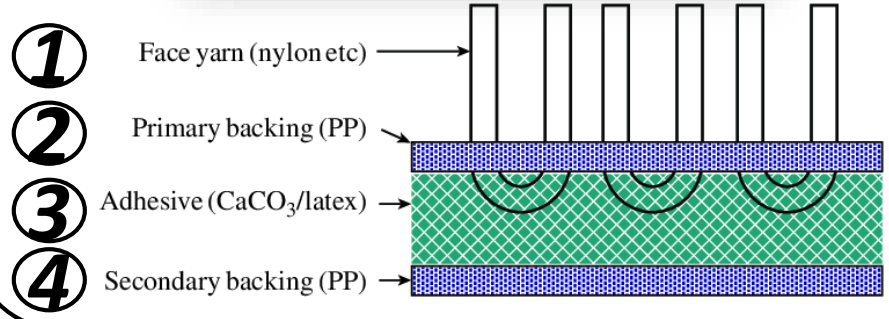
ECOLON

What makes Ecolon superior and reliable ?

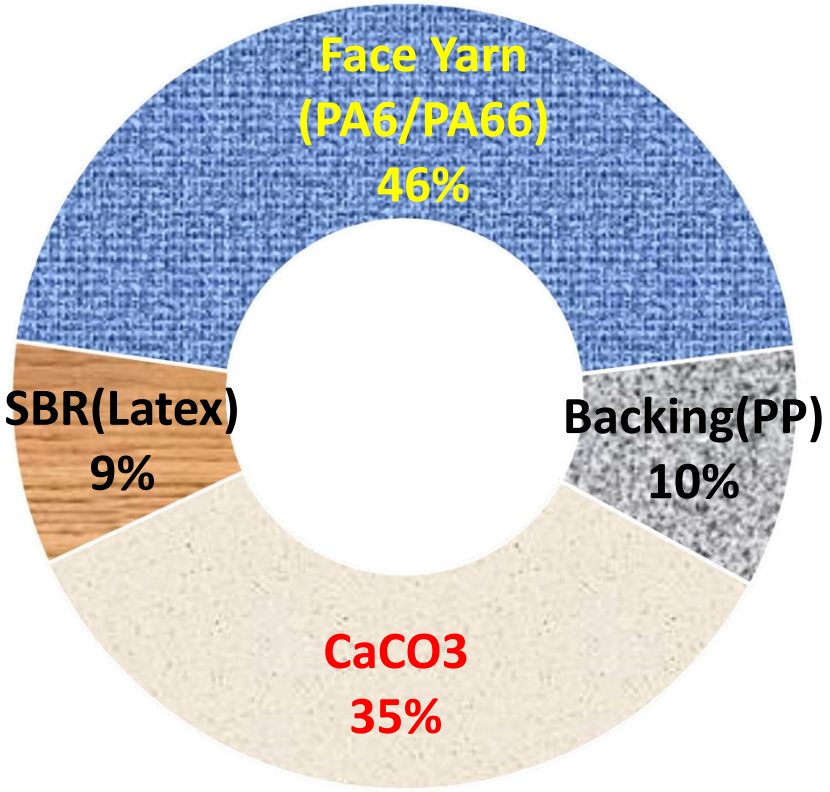
Carpet Structure & Material composition

Carpet Structure

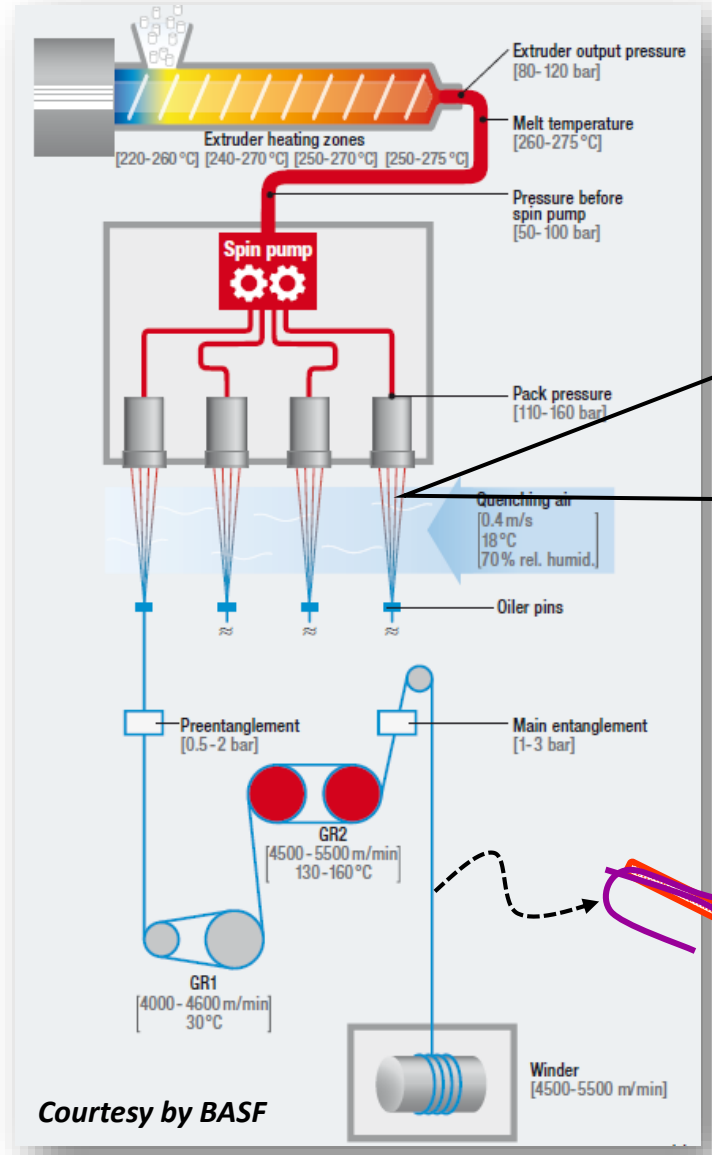




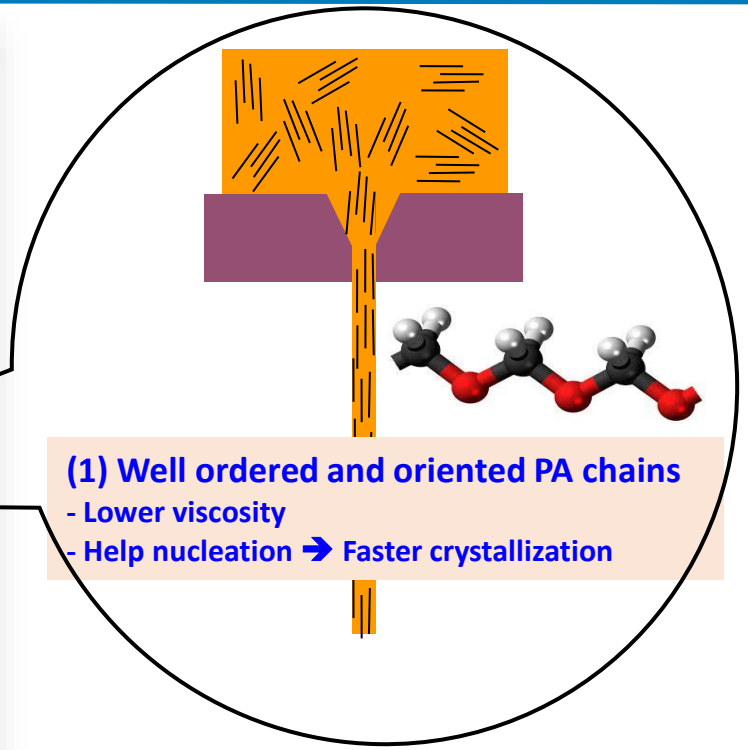
Material composition



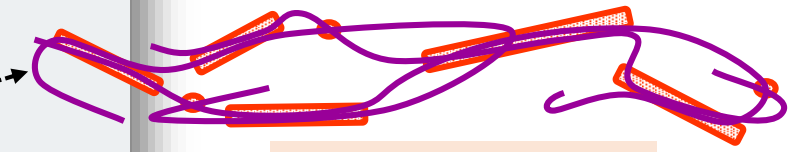
Rheological, Thermal Behavior of Carpet Fiber



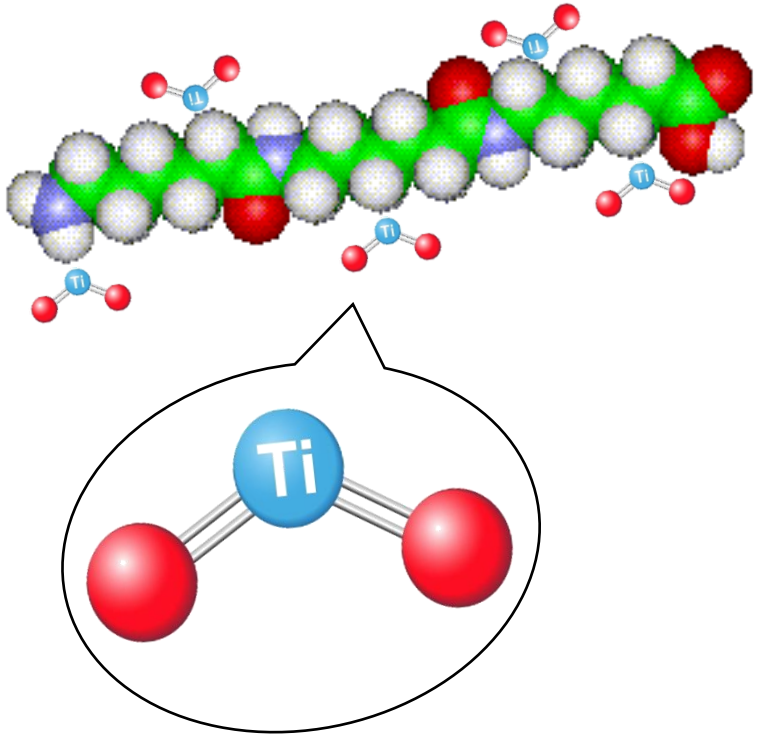
Courtesy by BASF



(1) Well ordered and oriented PA chains
- Lower viscosity
- Help nucleation ➔ Faster crystallization

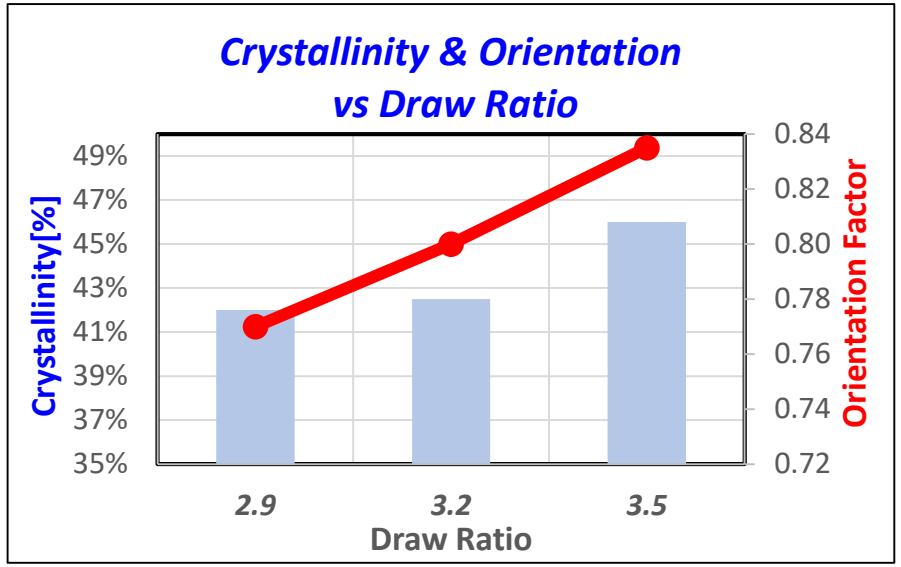


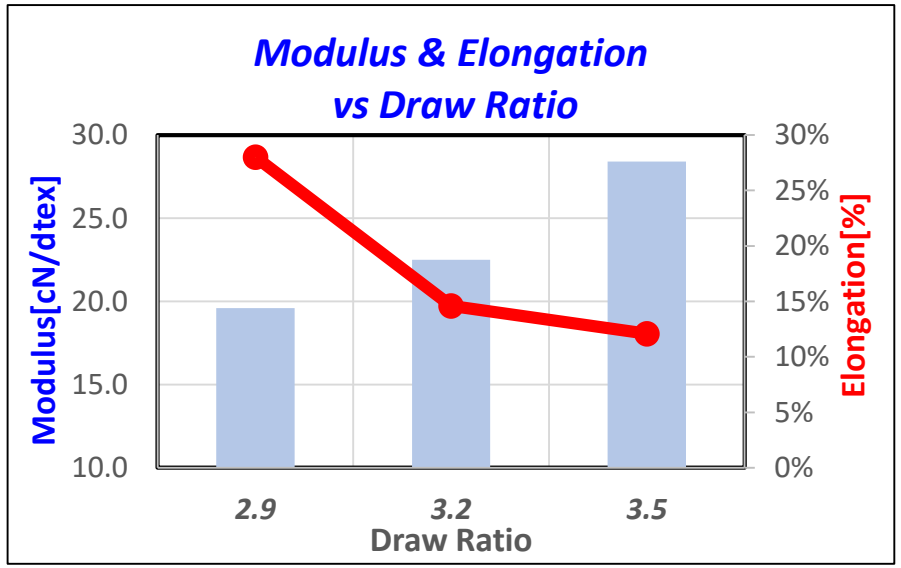
Ultra Stretched Spun



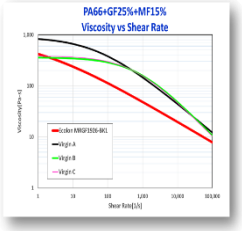
(2) TiO_2 acts as heterogeneous nucleating agents to facilitate crystallization.

Rheological, Thermal behavior of carpet fiber



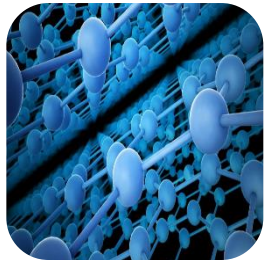


Carpet fiber has inherently



Good flow !

Rapid cooling !



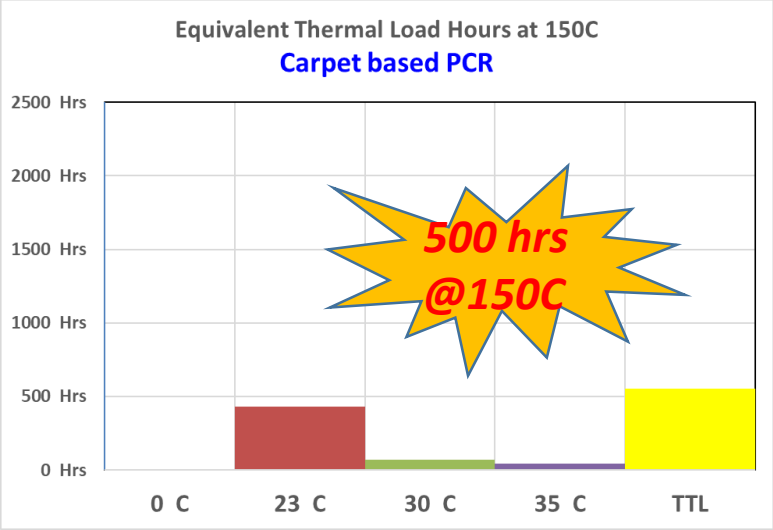
High Crystallinity

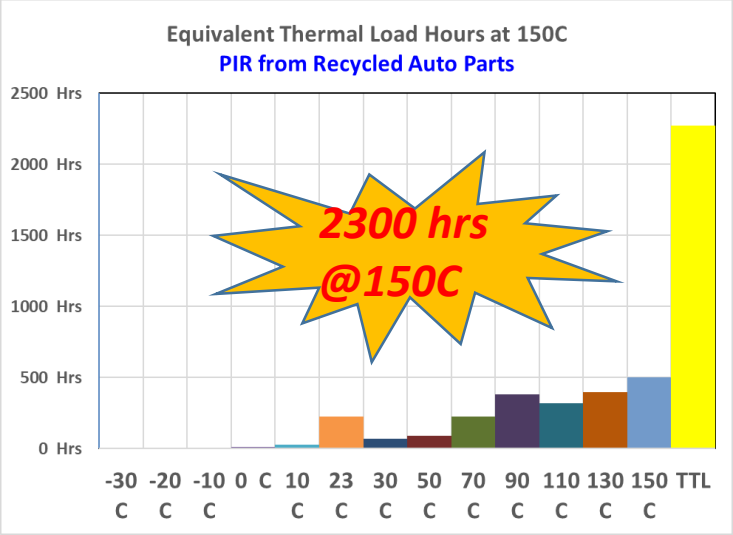
Thermo-oxidation degradation : 20 yrs

Equivalent thermal aging at 150C, after thermal history for 20 years

$$k = Ae^{\frac{-E_a}{RT}}$$

$$\tau_2 = \frac{\tau_1}{2^{\frac{T_2 - T_1}{\alpha}}}$$





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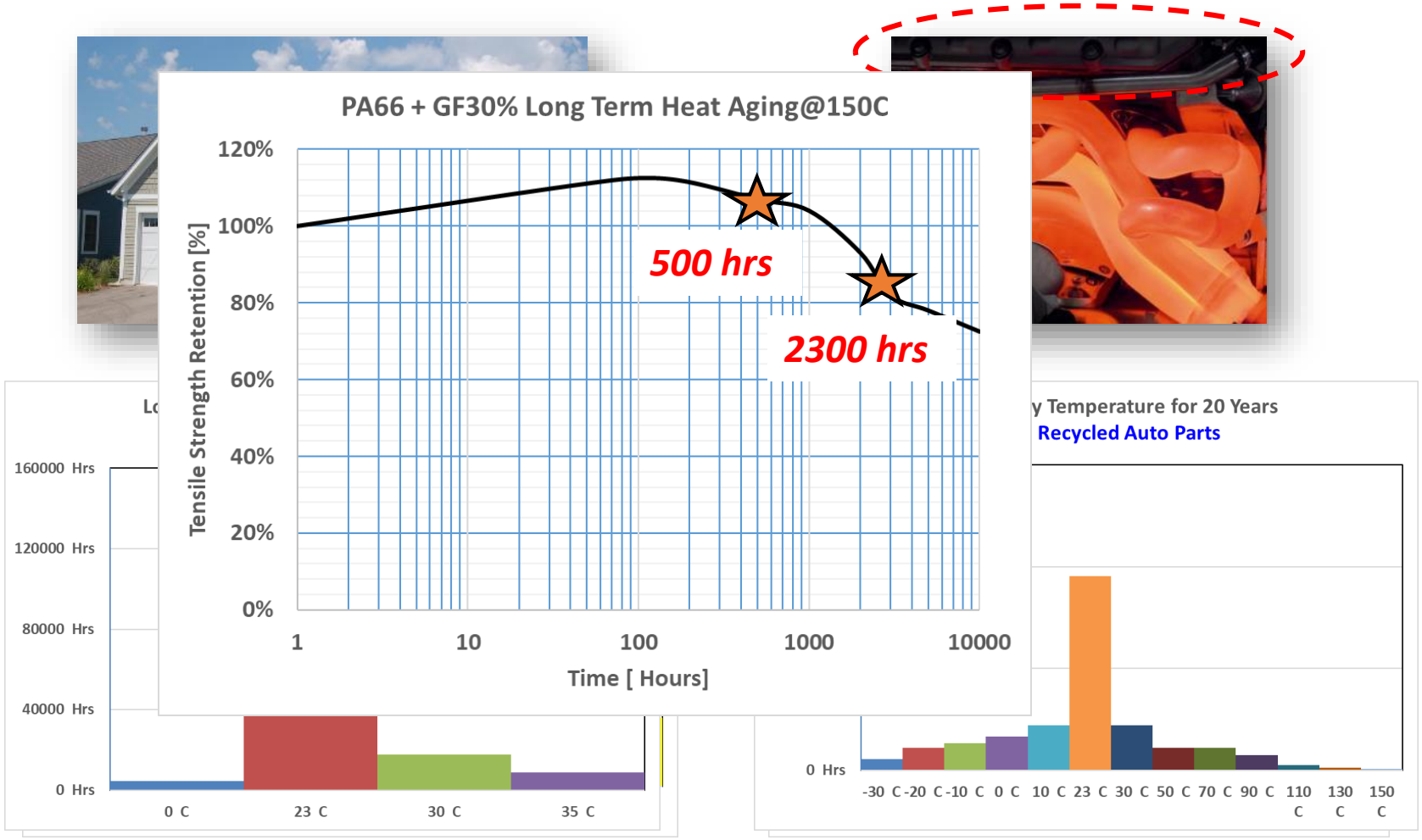


Thermo-oxidation degradation : 20 yrs

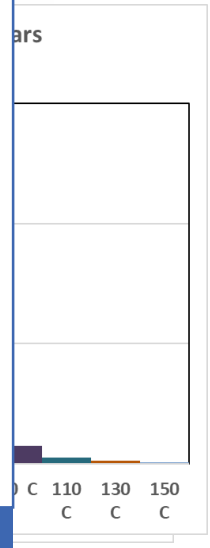
Equivalent thermal aging at 150C, after thermal history for 20 years

$k =$

$\tau_2 =$

Equivalent Thermal aging of carpet for 20 years

500 hours at 150C	**Minimum property loss**



02 Wellman Wet Separation Process and Advantage

Comparison of each recycling process

PRET WELLMAN

Chemical Separation (DePolymerization)

Advantage

- Purest Nylon
- No degradation in properties
- Perfect for fiber to fiber

Disadvantage

- Extreme CAPEX
- Only for PA6
- Limited capacity
- High cost than Virgin

Chemical Separation (Formic Acid)

Advantage

- 2nd purity
- Capable to process both PA6 and PA66
- Moderate CAPEX
- Cost effective Nylon fiber

Disadvantage

- Color residue
- Other form of recycling for non-Nylon part

Dry Separation

polymers
- High CAPEX for high volume op.

Wet & Dry Separation

- **Quality of incoming carpet is important**

Shearing or Skiving Separation

landfilled

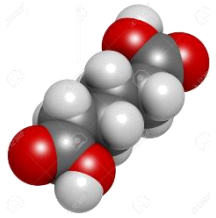
Advantage

- **Relatively high purity**
- **Excellent $/performance**
- **Capable to be used for plastic compounding**

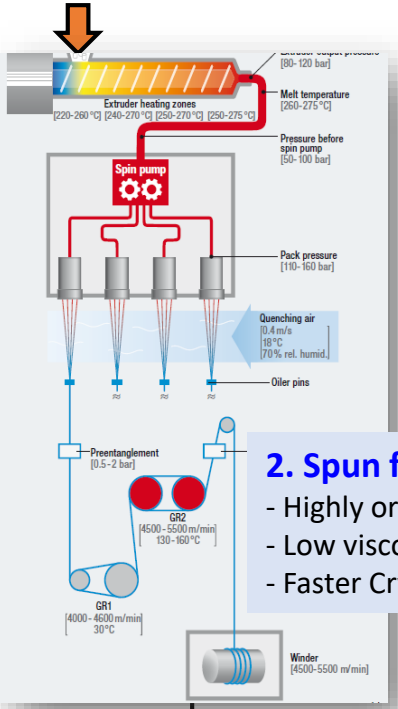
Disadvantage

- **Limited sources only available**
- **High CAPEX**
- **Quality of incoming carpet is important**

We convert waste carpet into Car Parts



1. Polymer for carpet yarn
- High molecular weight
- Low viscosity



2. Spun fiber yarn
- Highly ordered and oriented
- Low viscosity
- Faster Crystallization

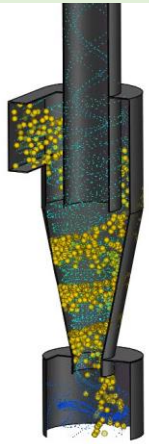
Courtesy by BASF

1999 → 2009 → 2019

3. Carpet

4. DRY Separation

5. WET Separation



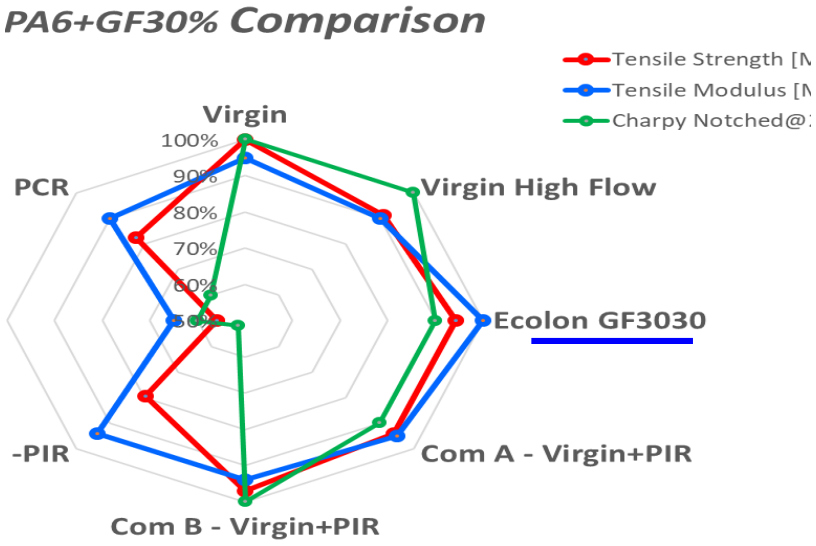
6. PCR PA
Feed Stock

7. Ecolon
Compounded into Ecolon for Auto PA parts

Advantage of Dry/Wet Separation Process

	PA6+GF30							
	Company E Virgin PA6	Company E Virgin PA6 Improved Flow	Recycled PA6 + GF30%					
			Wellman Ecolon GF3030	Comp. A (PIR)	Comp. A (Virgin + PIR)	Comp. B (Virgin + PIR)	Comp. D (PCR)	Comp. E (PCR)
Tensile Strength [MPa]	170	155	160	135	160	165	95	140
Tensile Modulus [MPa]	9,500	9,000	10,000	9,400	9,500	9,400	6,500	9,000
Charpy Notched@23C	10.0	10.0	9.0	5.2	9.0	10.0	6.0	6.0

DRY – WET separation process ensures the B.I.C mechanical properties



01. Carpet Based PCR Nylon Nature

02. Wellman Wet Separation Process and Advantage

03 Advantage of 100% PCR Ecolon

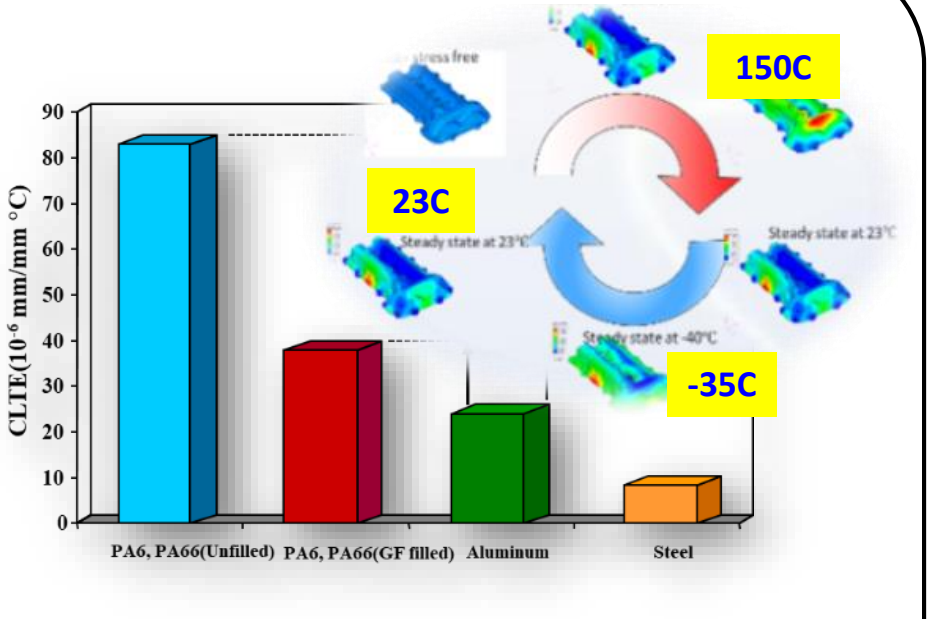
04. Importance of Process Development

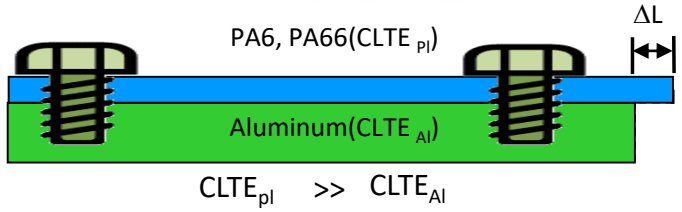
05. Ecolon for High Heat

06. Introduction to PRET/Wellman

Why does good flow matter ?

Stress by thermal expansion





$$\sigma_{expansion\_stress} = E \cdot \varepsilon = E \cdot \frac{\Delta L}{L} = E \cdot CLTE \cdot (T_2 - T_1)$$

Stress by thermal expansion

	Tensile strength	Tensile Modulus	CLTE
Flow Dir	**180**	9,500	2.E-05
Transverse	**90**	4,000	1.E-04

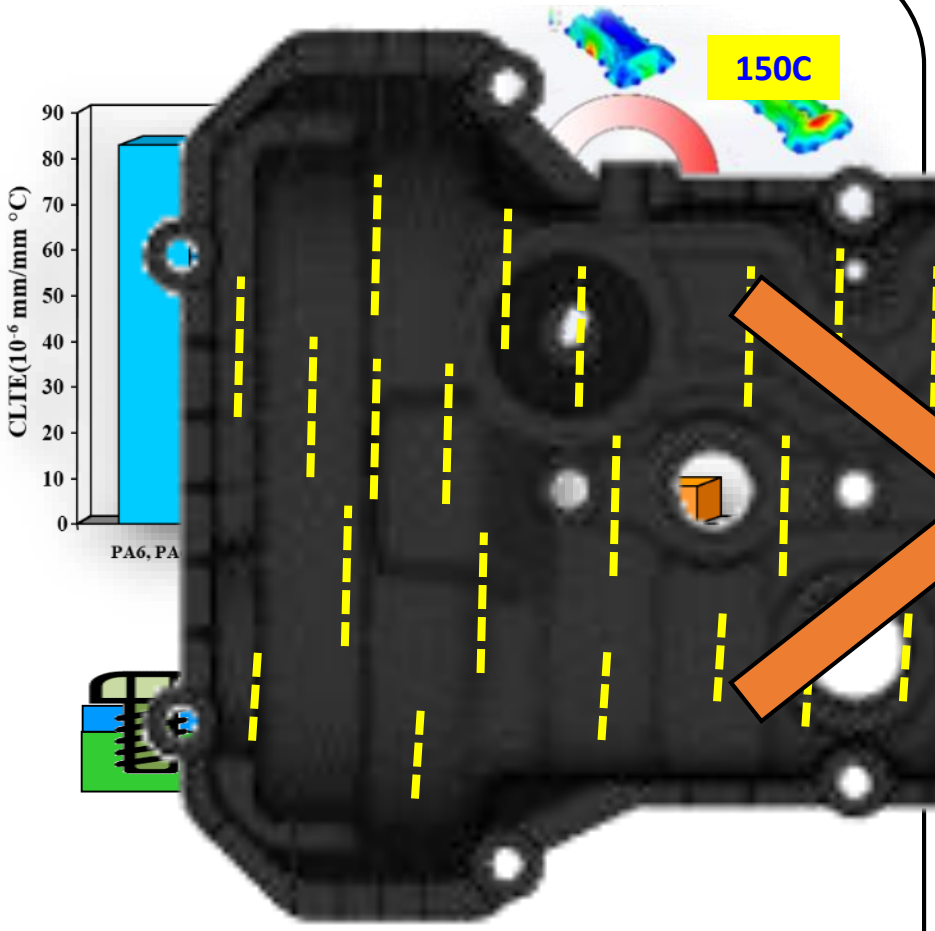
	ΔT (150 - 23C)	**Thermal Stress**	% [therm/tensile]
Flow Dir	127	**24.1**	**13%**
Trans. Dir	127	**50.8**	**56%**

For plastic parts exposed to high thermal cycling environment like engine parts, thermal stress handling according to GF orientation is more critical than plastic material's tensile strength itself.

Why does good flow matter ?

PRET WELLMAN

Stress by thermal expansion



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		4,000	1.E-04
			%
			[Therm/tensile]
			13%
		50.8	56%

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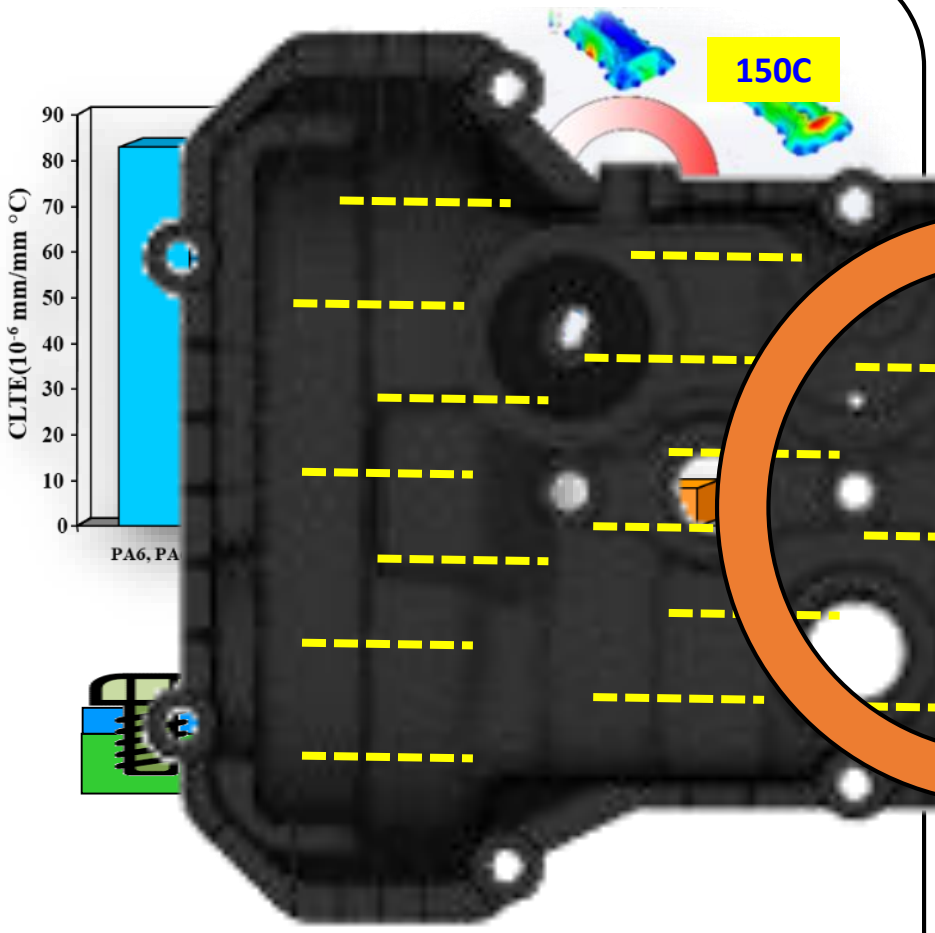

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Stress by thermal expansion

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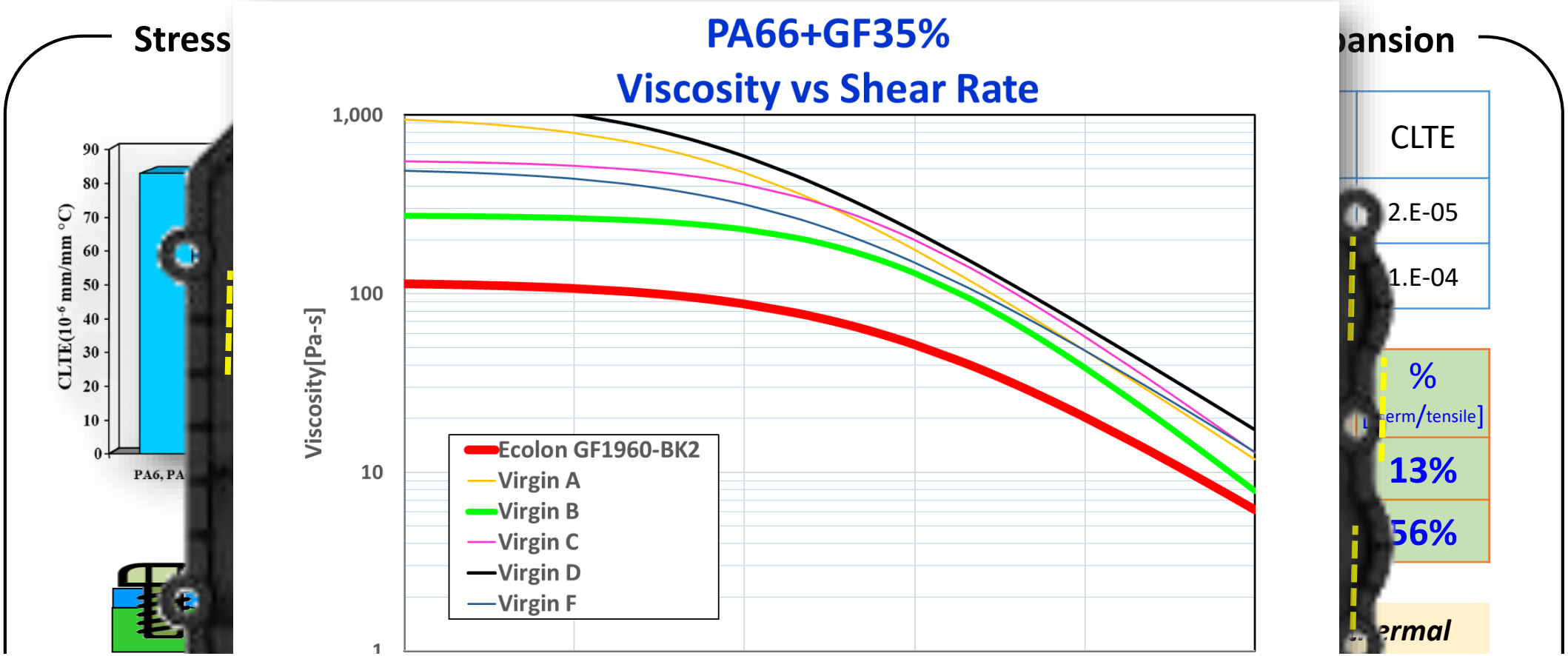
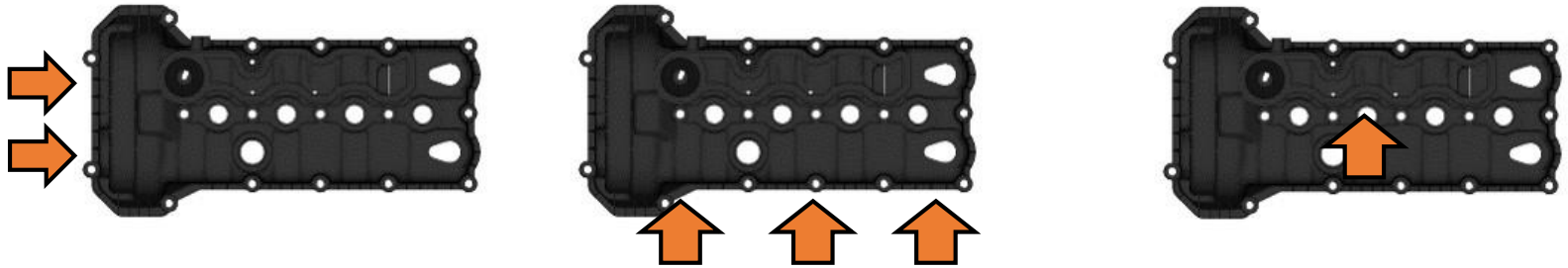


Good flow worth more than 25MPa Tensile Strength for big plastic E/G parts !

Engineering Challenge in Cam Cover

Rating

- **5 : Excellent**
- **3 : Fair**
- **1 : Poor**

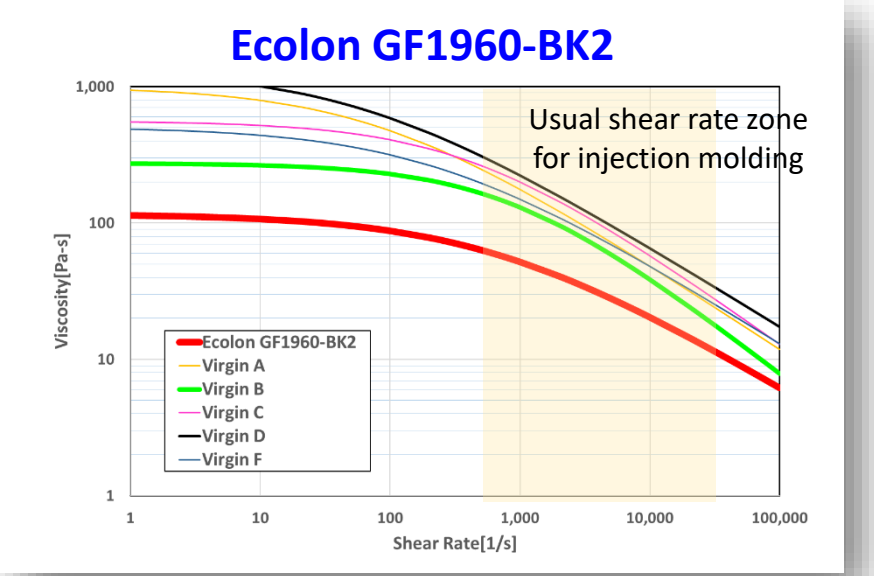


Injection Pressure & Clamp tonnage	3	4	4
Dimensional Control	3	4	1
Flatness Control	4	5	1
Thermal Stress Control	5	1	3
NVH (Related more to Cam cover shape)	3	4	3
Overall	3.6	3.6	2.4

PCR Ecolon Advantage for big part molding

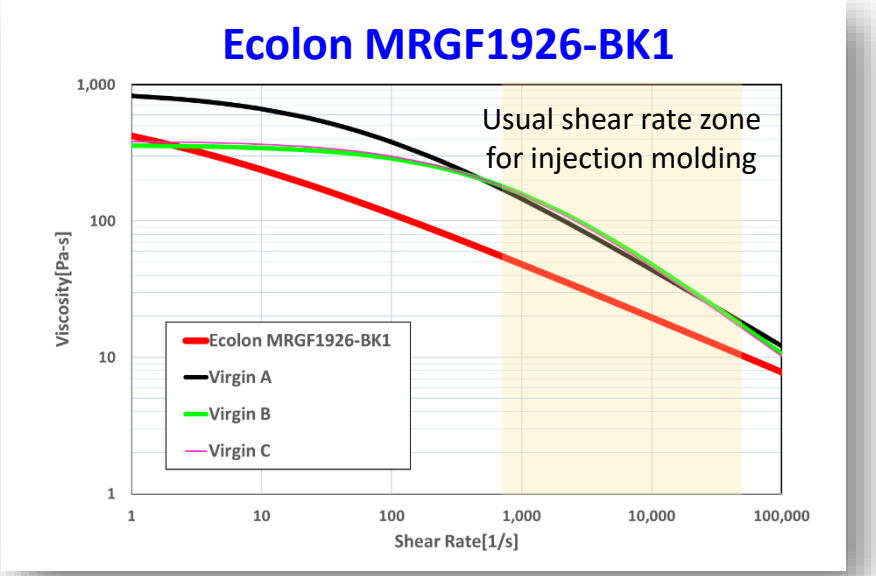
PRET WELLMAN

PA66 + GF 35%



1. Best-In-Class flow performance
2. Shear thinning at mid-high speed
3. Excellent for big parts molding

PA66 + (MF+GF) 40%



1. Best-In-Class flow performance
2. Excellent shear thinning
3. Easy process setup : Max V

PCR Ecolon Advantage for productivity

PRET WELLMAN

Theoretic cooling time

Material thermal properties dependent

Part thickness, shape and design dependent

Process & Tool design dependent

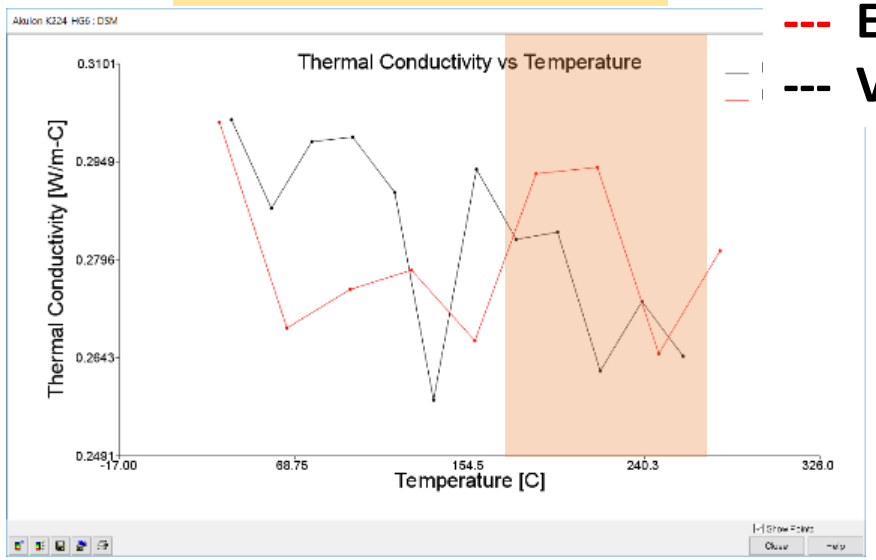
$$\tau_{cooling} = \frac{\rho \cdot C \cdot a \cdot t^2}{k} \cdot \ln\left(\frac{T_{melt} - T_{mold}}{T_{eject} - T_{mold}}\right)$$

(1) Well ordered and oriented molecular structures

(2) TiO_2 : Heterogeneous nucleating agents

Fast crystallization. ➔ Shorter cycle time

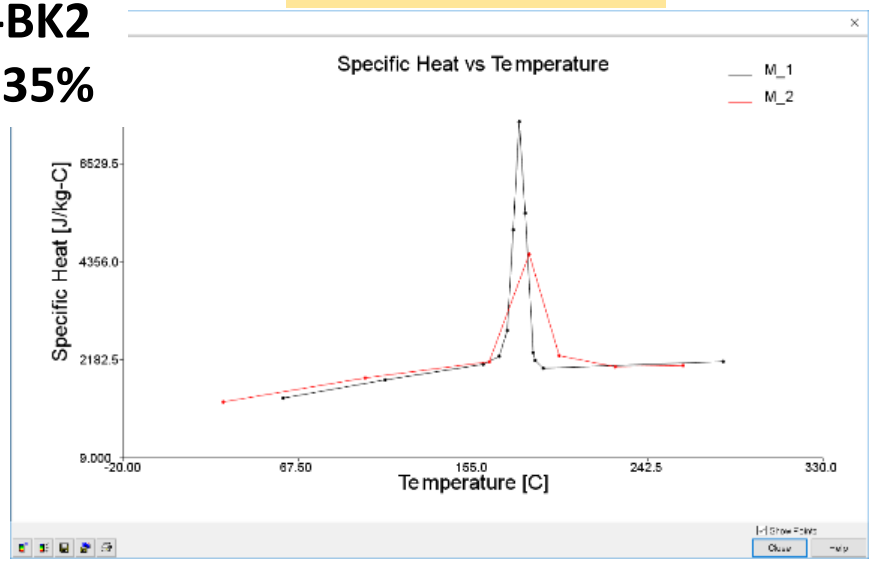
Thermal conductivity



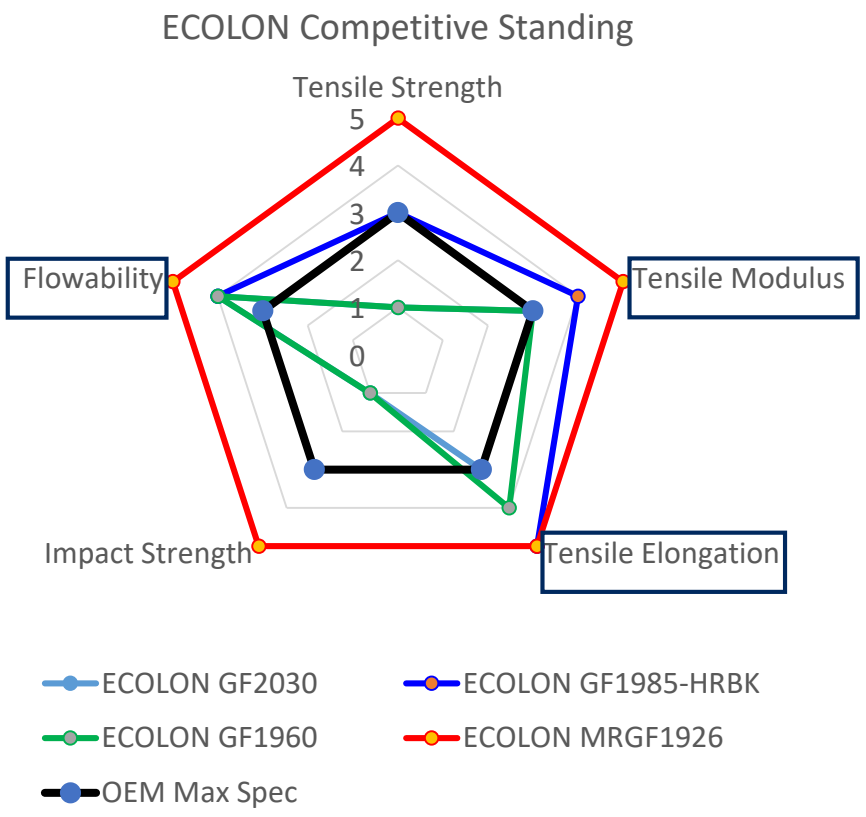
--- Ecolon GF1960-BK2

--- Virgin PA66+GF35%

Specific Heat



Carpet based PCR competitive rating



Best Fit

- Tensile Modulus
- Flow ability
- Cam cover, E/G cover, F/Shroud, NVH, etc

Fair Fit

- Tensile strength
- Intake Manifold, Tanks & Reservoir, Mounts, Bracket, etc

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05. Ecolon for High Heat

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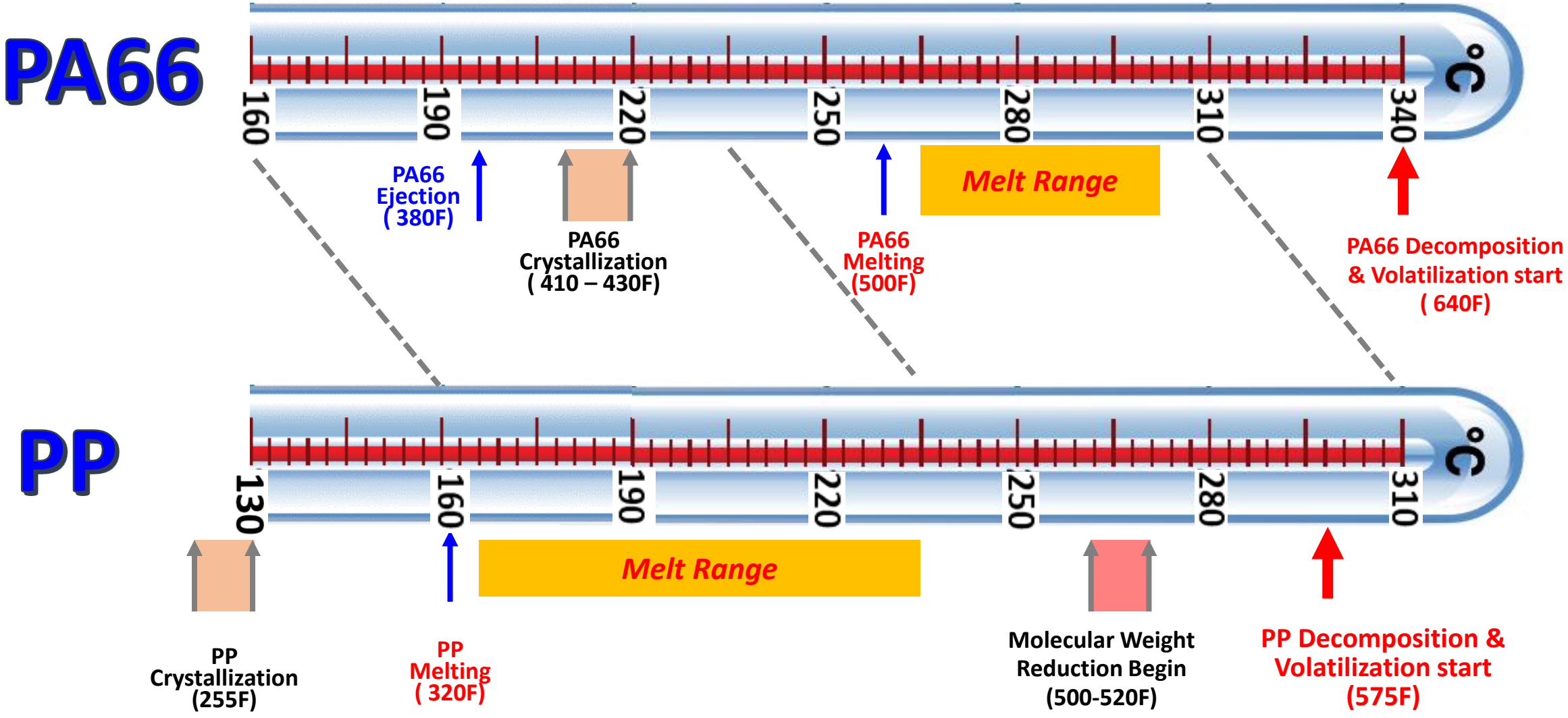
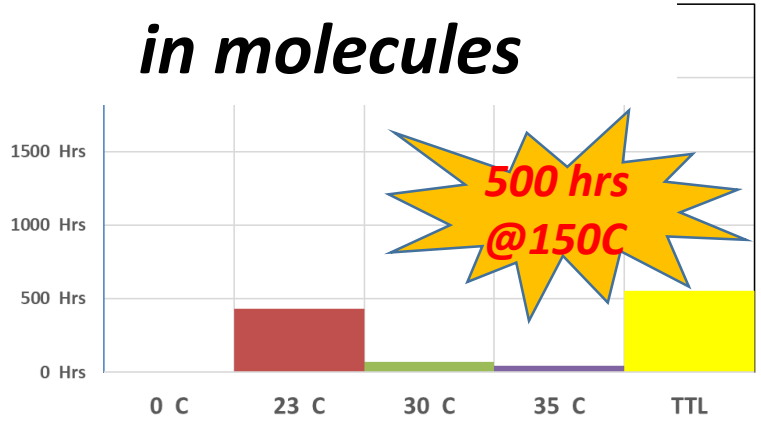
Thermal transition point : PA *vs* PP

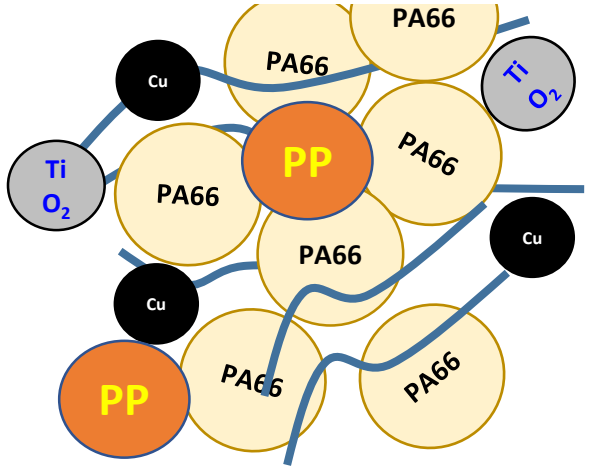


Importance of process window

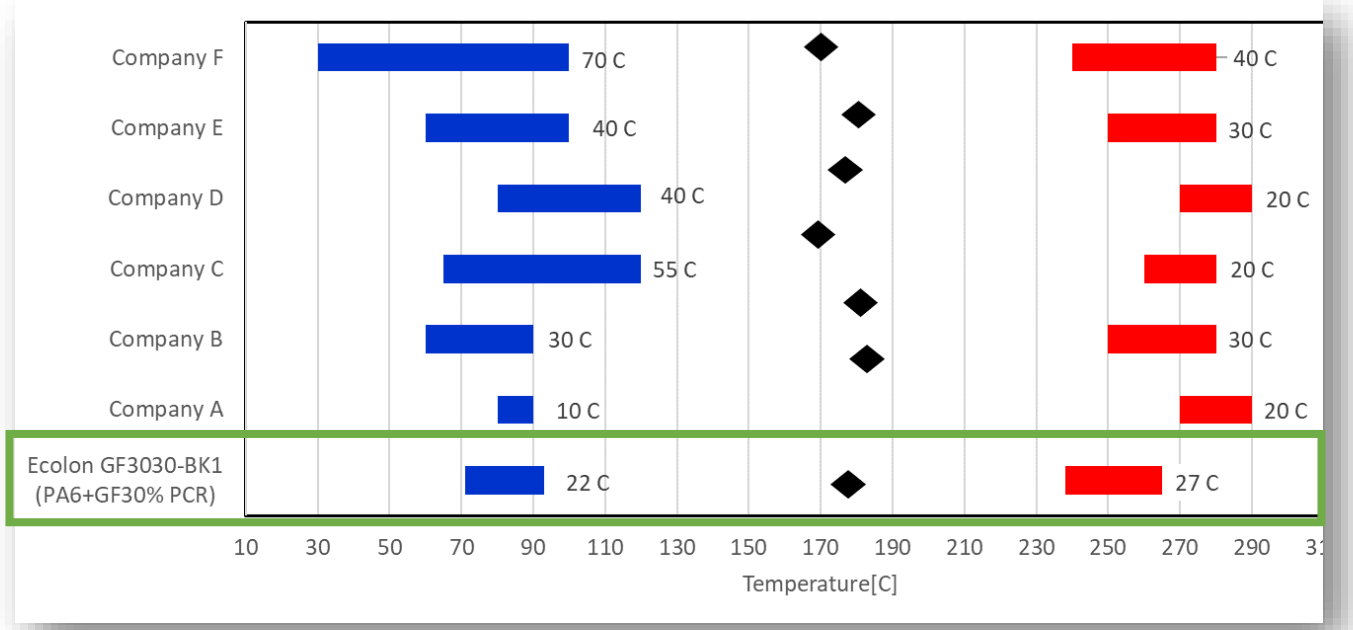
(1) Thermal History in molecules



(2) Small PP Contents

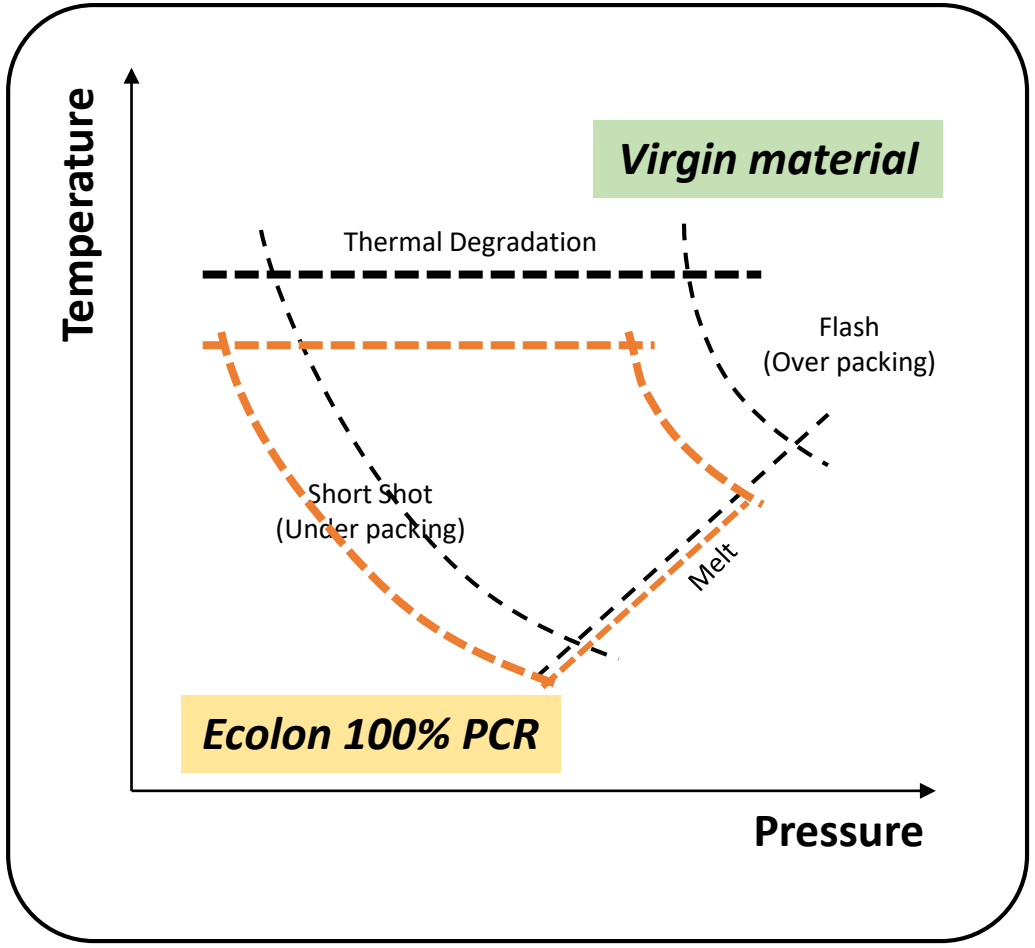


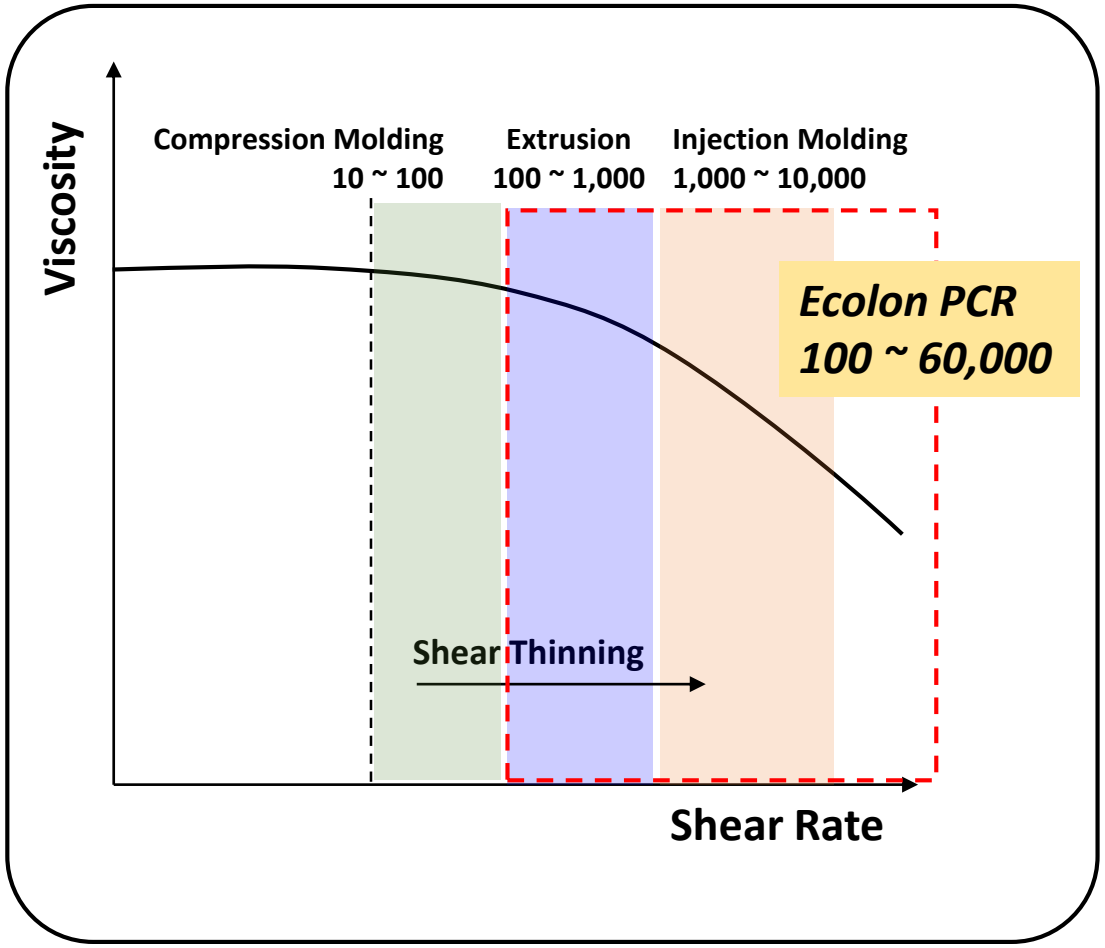
Sensitivity to Temperature



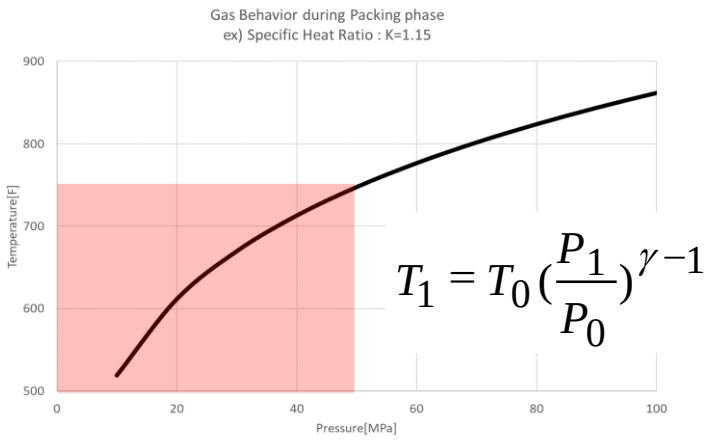
Thermal history in PCR molecules and small unseparated PP contents makes Ecolon PCR resin quite sensitive to high temperature. ➔ Special care when applying high melt temperature

Importance of process window

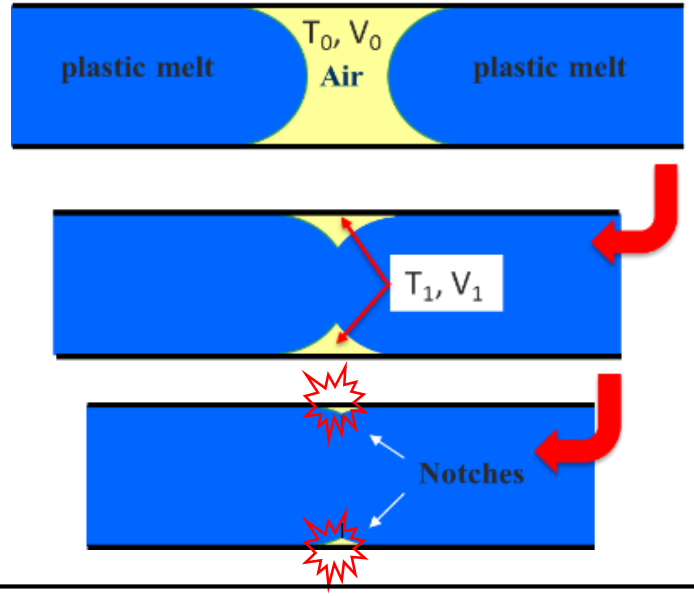




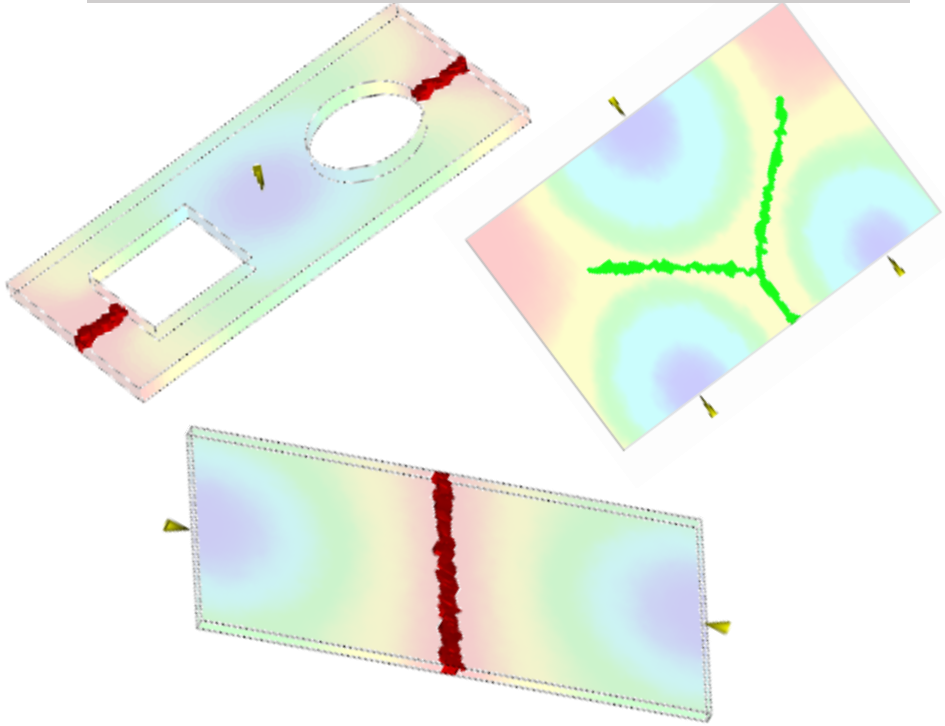
Importance of gas handling



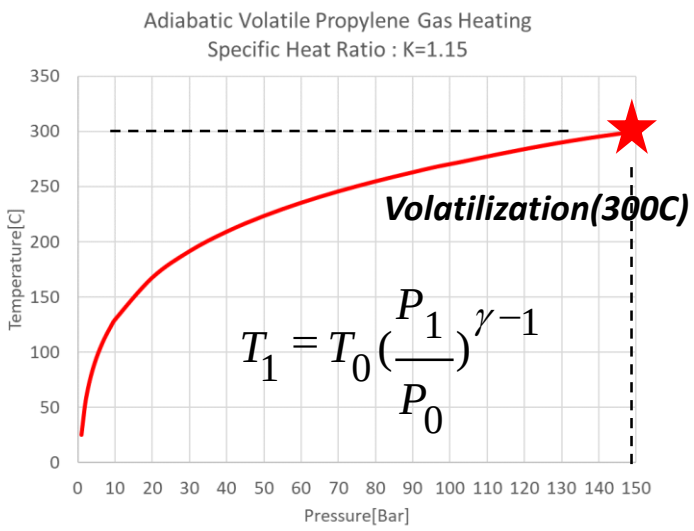
$$T_1 = T_0 \left(\frac{P_1}{P_0}\right)^{\gamma - 1}$$

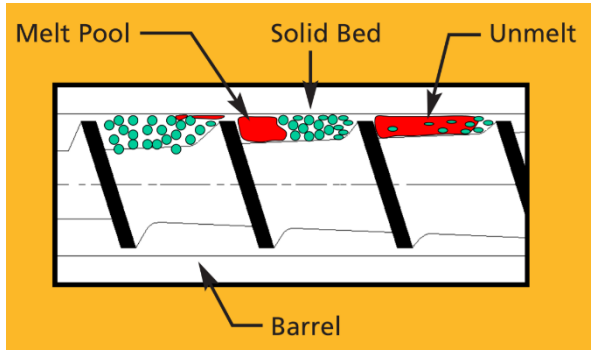


With gas present, high packing pressure can cause plastic material intact with compressed gas easily to degrade due to high compression heating. ➔ Poor weld line strength



Back Pressure Control





Typical screw compression ratio = 2.5 ~ 4 : 1

1) *Typical injection molding screw Compression Ratio 2.5:1 ~ 4:1*

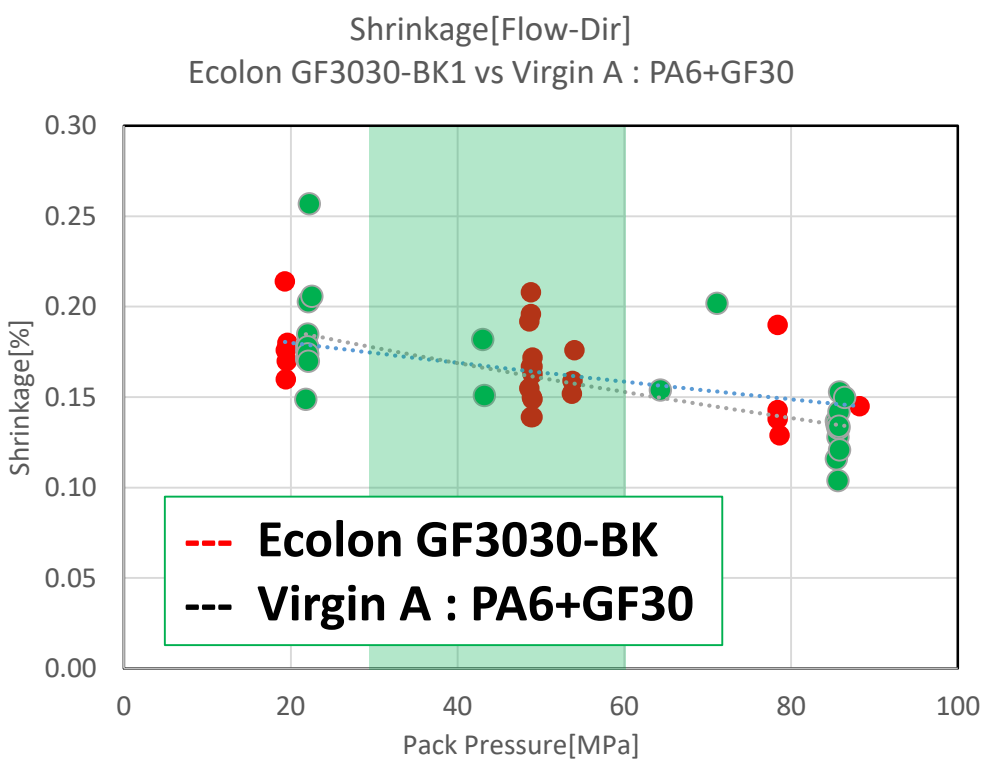
2) *Considering Propylene's adiabatic gas compression process and volatilization at 300C, max pressure allowed : 150 bar*

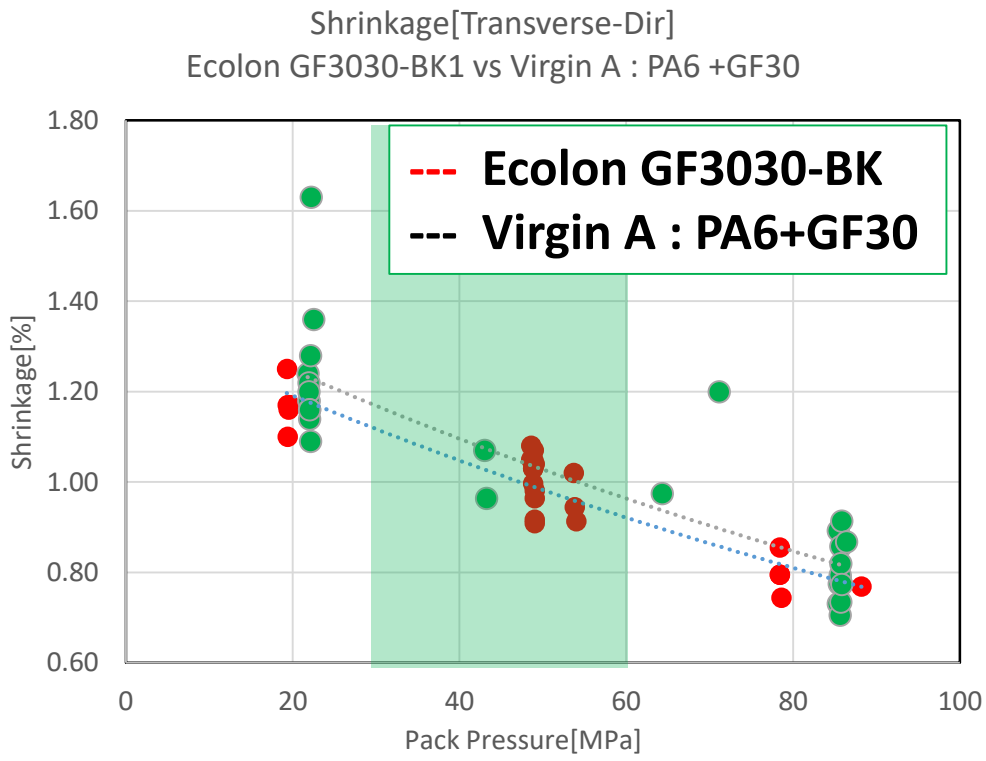
3) *Max back pressure range recommended : 40 ~ 50 bar (600 ~ 700 psi max)*

Back Pressure Setting for Ecolon

- *The lower, the better*
- *Maximum back pressure not to exceed 40-50 bar*

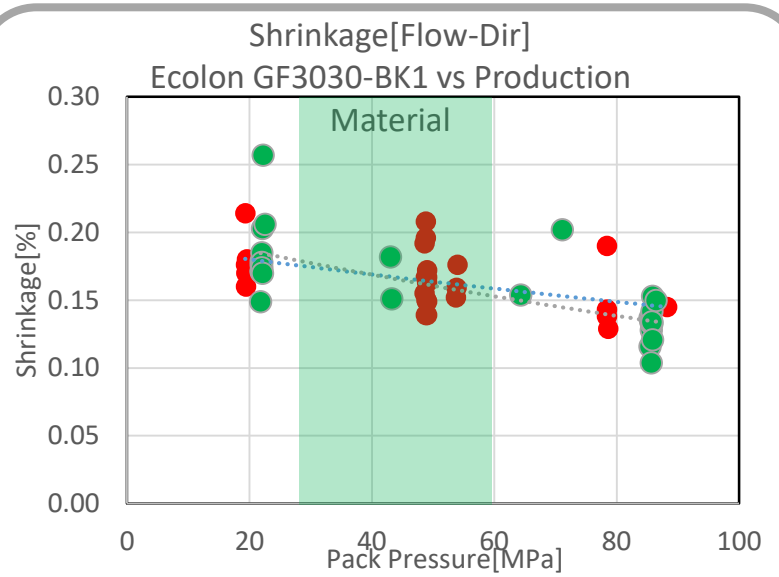
Dimensional control : Shrinkage

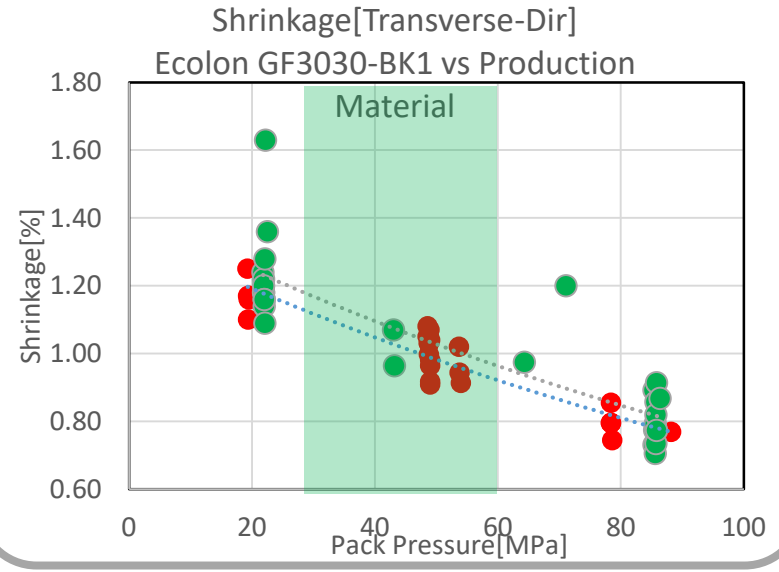


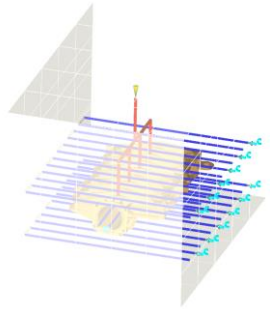


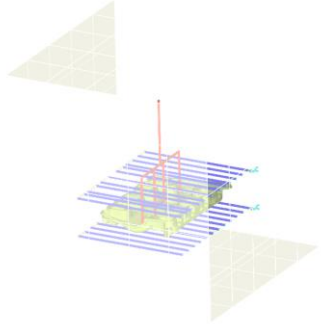
1. **Flow directional Shrinkage**
   - **Compatible** with most virgin GF grades
2. **Transverse directional Shrinkage**
   - **Slightly lower shrink rate** than most virgin GF grades ➔ **Packing condition should be reduced to match with virgin dimension**

Importance of CAE for dimensional control







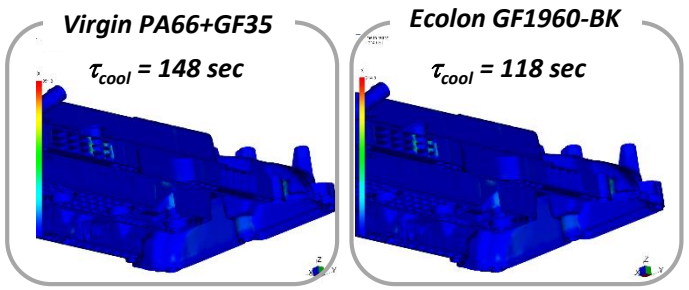


		Mid Shell								
Parameters		Production Material	Production Material	Production Material	Ecolon GF3030-BK1	Ecolon GF3030-BK1	Ecolon GF3030-BK1	Ecolon GF3030-BK1	Ecolon GF3030-BK1	Ecolon GF3030-BK1
Temperature	T_{melt}	276 C	276 C	276 C	276 C	276 C	276 C	276 C	276 C	285 C
	$T_{cooling}$	35 C	35 C	60 C	35 C	60 C	35 C	35 C	70 C	85 C
V/P transfer		95%	95%	95%	95%	95%	95%	95%	95%	99%
Time	t_{fill}	3.5 sec	2.6 sec	3.5 sec	3.5 sec	3.5 sec	2.0 sec	2.0 sec	2.0 sec	1.9 sec
	t_{pack}	4.0 sec	4.0 sec	4.0 sec	4.0 sec	4.0 sec	4.0 sec	4.0 sec	4.0 sec	2.0 sec
	t_{hold}	8.0 sec	8.0 sec	8.0 sec	8.0 sec	8.0 sec	8.0 sec	8.0 sec	8.0 sec	0.0 sec
	t_{cycle}	76.5 sec	76.5 sec	76.5 sec	76.5 sec	76.5 sec	76.5 sec	76.5 sec	76.5 sec	76.5 sec
Pressure	P_{max_fill}	57 MPa	60 MPa	53 MPa	57 MPa	57 MPa	57 MPa	40 MPa	40 MPa	20 MPa
	P_{pack}	57 MPa	57 MPa	57 MPa	57 MPa	57 MPa	57 MPa	40 MPa	40 MPa	20 MPa
	P_{hold}	38 MPa	38 MPa	38 MPa	38 MPa	38 MPa	38 MPa	20 MPa	20 MPa	0 MPa
Tonnage		860 T	865 T	870 T	870 T	880 T	880 T	600 T	600 T	290 T
Shot Weight@Fill		1923 g	121 g	1924 g	2016 g	2017 g	2008 g	1954 g	1991 g	1948 g
Shot Weight@Max		2037 g	2036 g	2025 g	2082 g	2073 g	2080 g	2064 g	2049 g	1976 g
Shot Weight@Final		2020 g	2018 g	2005 g	2065 g	2053 g	2062 g	2056 g	2039 g	1960 g
Shear Rate@95%(Pack)		232	242	233	102	18	81	1600	4	44
Shear Rate@95%(Fill)		16000	20000	16000	19600	19600	33000	33140	33150	35900
Warpage [mm]	X-Dir	-1.3	-1.3	-1.4	-0.9	-1.0	-0.9	-1.0	-1.0	-1.2
		1.3	1.3	1.4	0.9	0.9	0.9	0.9	1.0	1.3
	Y-Dir	-1.6	-1.7	-1.7	-1.2	-1.2	-1.1	-1.1	-1.2	-1.6
		2.3	2.3	2.4	1.6	1.8	1.6	1.7	1.8	2.5
	Z-Dir	-1.6	-1.6	-1.7	-1.0	-1.0	-1.0	-1.0	-1.1	-1.5
		1.6	1.7	1.7	1.1	1.1	1.1	1.1	1.2	1.4
Shrinkage [mm]	δ x_max2min	2.6	2.6	2.8	1.8	1.9	1.8	1.9	2.0	2.5
	δ y_max2min	3.9	4.0	4.1	2.8	3.0	2.7	2.8	3.0	4.1
	δ x_2_base	Base	0.0	0.2	-0.8	-0.7	-0.8	-0.7	-0.6	-0.1
	δ y_2_base	Base	0.1	0.2	-1.1	-0.9	-1.2	-1.1	-0.9	0.2

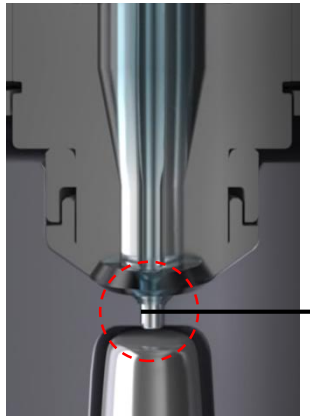
		Lower Shell			
Parameters		Production Material	Ecolon GF3030-BK1	Ecolon GF3030-BK1	Ecolon GF3030-BK1
Temperature	T_{melt}	277 C	277 C	285 C	277 C
	$T_{cooling}$	35 C	35 C	85 C	70 C
V/P transfer		90%	90%	99%	90%
Time	t_{fill}	3.6 sec	2.2 sec	2.2 sec	2.3 sec
	t_{pack}	3.0 sec	3.0 sec	2.0 sec	3.0 sec
	t_{hold}	10.0 sec	10.0 sec	0.0 sec	10.0 sec
	t_{cycle}	71.0 sec	71.0 sec	71.0 sec	71.0 sec
Pressure	P_{max_fill}	75 MPa	27 MPa	25 MPa	27 MPa
	P_{pack}	49 MPa	49 MPa	20 MPa	35 MPa
	P_{hold}	31 MPa	31 MPa	0 MPa	15 MPa
Tonnage		720 T	715 T	265 T	490 T
Shot Weight@Fill		1802 g	1837 g	1811 g	1826 g
Shot Weight@Max		1895 g	1908 g	1849 g	1883 g
Shot Weight@Final		1895 g	1908 g	1837 g	1883 g
Shear Rate@95%(Pack)		142	2114	287	805
Shear Rate@95%(Fill)		27460	53360	58180	53500
Warpage [mm]	X-Dir	-1.1	-1.1	-1.6	-1.3
		1.1	1.0	1.4	1.1
	Y-Dir	-2.3	-2.0	-2.6	-2.3
		2.2	1.9	2.3	2.1
	Z-Dir	-1.0	-0.9	-1.1	-0.8
		1.7	1.7	2.1	1.9
Shrinkage [mm]	δ x_max2min	2.2	2.1	3.0	2.4
	δ y_max2min	4.5	3.9	4.9	4.4
	δ x_2_base	Base	-0.1	0.8	0.2
	δ y_2_base	Base	-0.6	0.4	-0.1

		Upper Shell						
Parameters		Production Material	Ecolon GF3030-BK1	Ecolon GF3030-BK1	Ecolon GF3030-BK1	Ecolon GF3030-BK1	Ecolon GF3030-BK1	Ecolon GF3030-BK1
Temperature	T_{melt}	275 C	275 C	275 C	275 C	285 C	275 C	275 C
	$T_{cooling}$	38 C	38 C	70 C	70 C	85 C	70 C	70 C
V/P transfer		80%	80%	80%	80%	99%	95%	95%
Time	t_{fill}	2.5 sec	1.4 sec	1.5 sec	1.6 sec	1.6 sec	1.7 sec	1.7 sec
	t_{pack}	3.5 sec	3.5 sec	3.5 sec	3.5 sec	2.0 sec	2.0 sec	2.0 sec
	t_{hold}	5.0 sec	5.0 sec	5.0 sec	5.0 sec	0.0 sec	3.0 sec	3.0 sec
	t_{cycle}	63.0 sec	63.0 sec	63.0 sec	63.0 sec	63.0 sec	63.0 sec	63.0 sec
Pressure	P_{max_fill}	62 MPa	49 MPa	35 MPa	25 MPa	21 MPa	24 MPa	25 MPa
	P_{pack}	49 MPa	49 MPa	35 MPa	25 MPa	20 MPa	20 MPa	25 MPa
	P_{hold}	38 MPa	38 MPa	20 MPa	15 MPa	0 MPa	10 MPa	15 MPa
Tonnage		610 T	600 T	415 T	280 T	230 T	215 T	280 T
Shot Weight@Fill		1384 g	1409 g	1403 g	1403 g	1393 g	1404 g	1404 g
Shot Weight@Max		1461 g	1492 g	1470 g	1465 g	1427 g	1446 g	1451 g
Shot Weight@Final		1450 g	1490 g	1468 g	1465 g	1415 g	1446 g	1448 g
Shear Rate@95%(Pack)		232	4562	1972	595	458	307	574
Shear Rate@95%(Fill)		4818	9600	9600	9600	9920	9600	9600
Warpage [mm]	X-Dir	-1.2	-0.9	-1.0	-1.0	-1.1	-1.0	-1.0
		1.2	0.9	1.0	1.0	1.2	1.1	1.1
	Y-Dir	-3.8	-2.7	-3.3	-3.4	-4.2	-3.8	-3.7
		3.8	2.7	3.2	3.3	4.1	3.7	3.6
	Z-Dir	-2.3	-1.6	-2.1	-2.1	-2.7	-2.4	-2.4
		4.9	3.5	4.3	4.5	6.1	5.2	5.0
Shrinkage [mm]	δ x_max2min	2.4	1.8	2.0	2.0	2.3	2.1	2.1
	δ y_max2min	7.6	5.4	6.5	6.7	8.3	7.5	7.3
	δ x_2_base	Base	-0.6	-0.4	-0.4	-0.1	-0.3	-0.3
	δ y_2_base	Base	-2.2	-1.1	-0.9	0.7	-0.1	-0.3

Process control with valve gate



Valve gate **nozzle tip freezing**
Before valve gate closing



How to prevent nozzle tip freezing ?

Usual mistake

Cause : Too cold nozzle tip temp. ?

Fix : Raise valve gate temp.

Degradation & Gas

Clogging by Agglomeration

Weak weld line

Unstable process

Longer cycle time

Recommendation

Cause : Fast PCR crystallization

Fix : Minimize SFT(Screw Forward T.)

Elimination of Hold Phase

Gate closure by valve gate

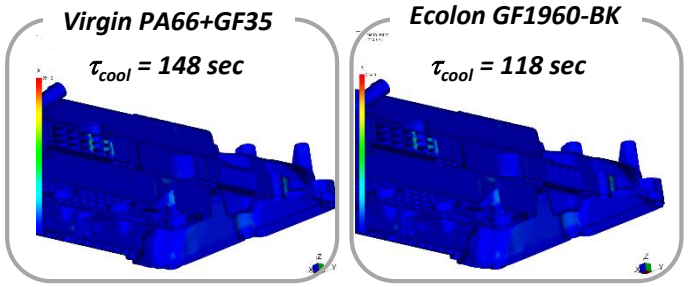
Smooth valve gate OP.

Good quality

Consistency

Shorter cycle time

Process control with valve gate



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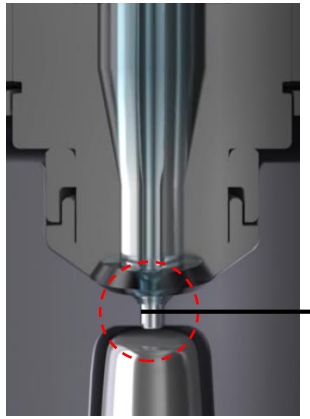

How to prevent nozzle tip freezing ?

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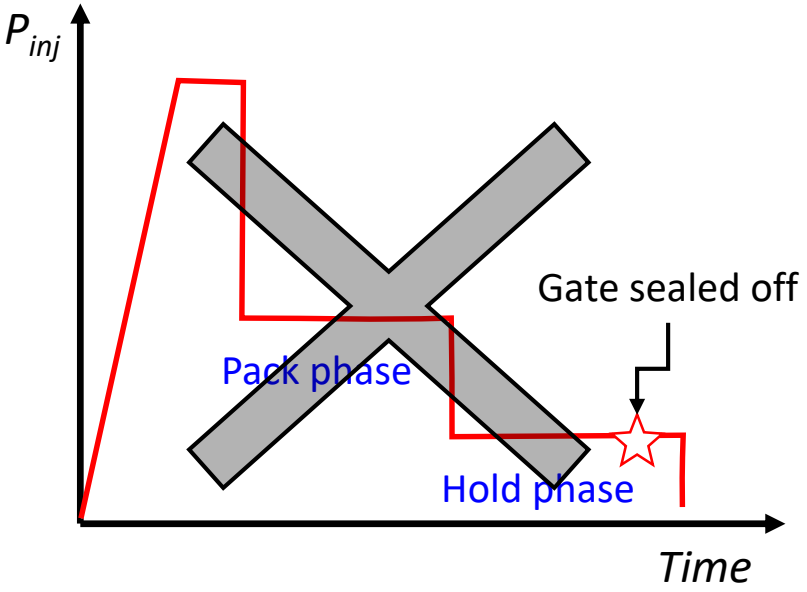
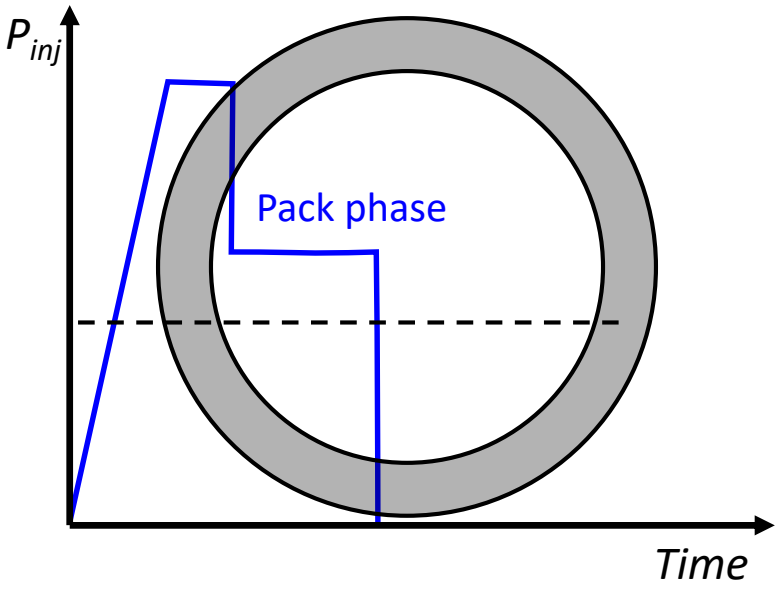
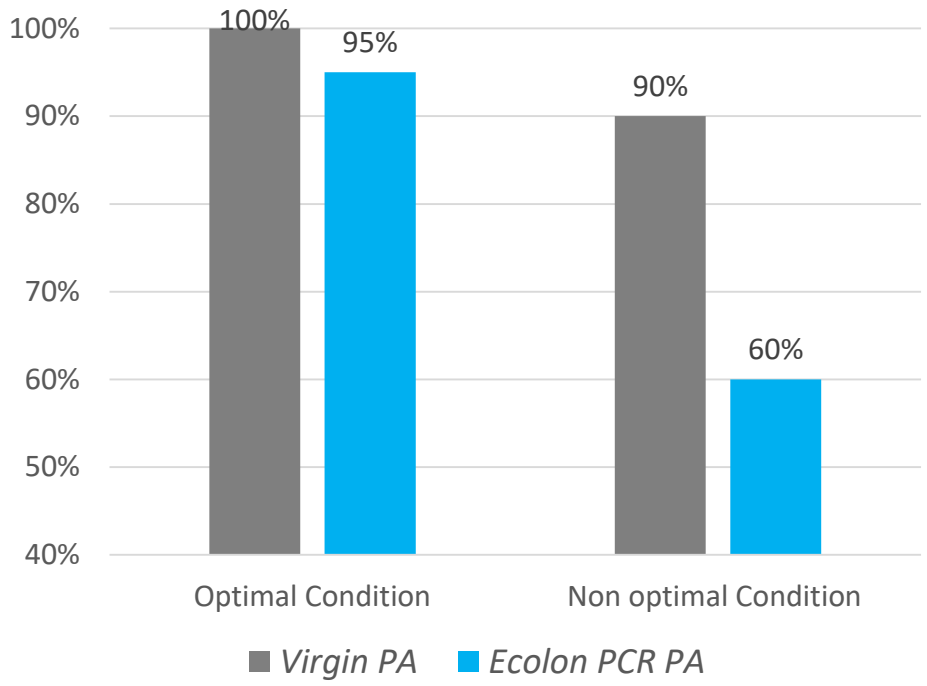




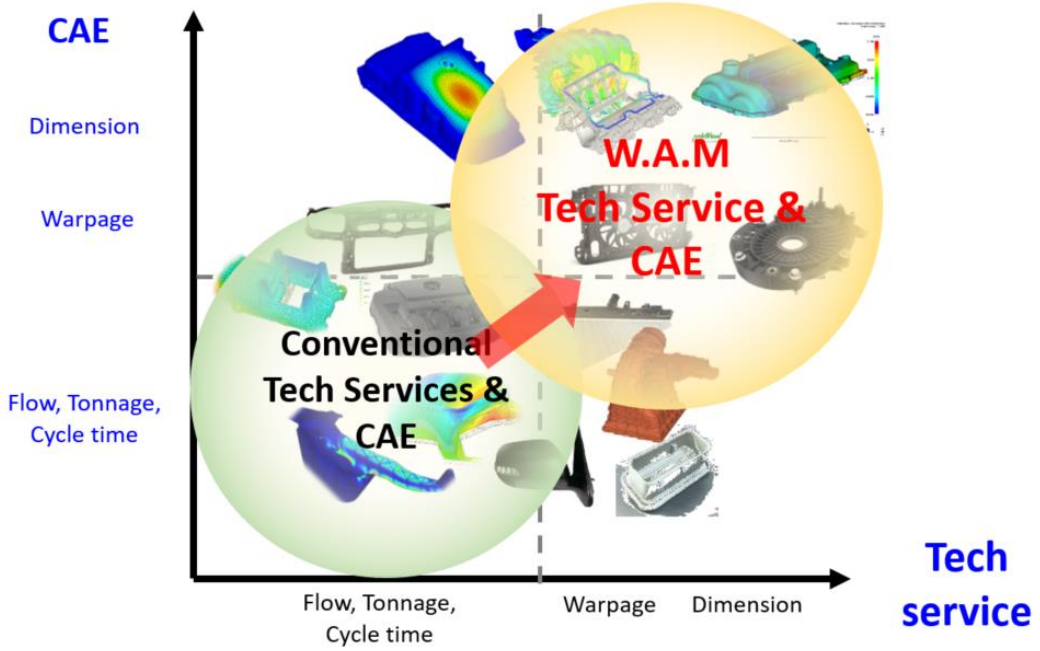
Importance of Process Optimization

PRET WELLMAN

Importance of Processing Condition



Turn-key CAE & Tech Service



Process optimization is the key to achieve 95% virgin PA performance

Wellman CAE & Tech Service supports clients to achieve the best performance as available.

01. Carpet Based PCR Nylon Nature

02. Wellman Wet Separation Process and Advantage

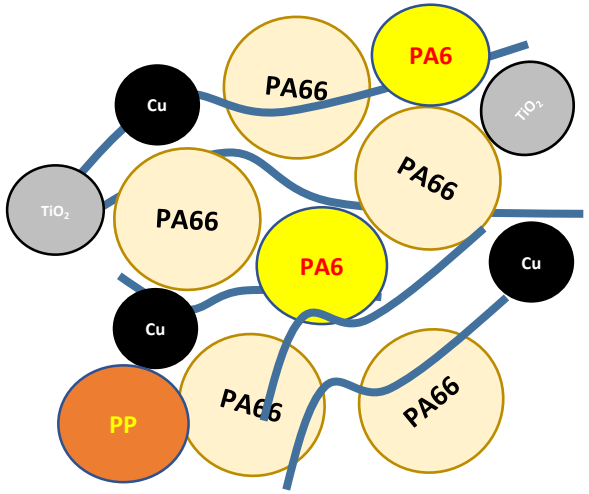
03. Advantage of 100% PCR Ecolon

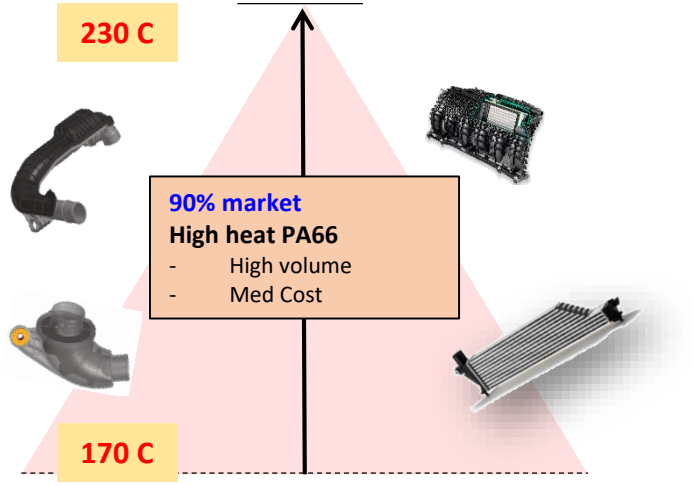
04. Importance of Process Development

05 Ecolon for High Heat

06. Introduction to PRET/Wellman

Ecolon High heat PA66++





"PP" or "PA6" : Not "Contamination", But "Natural Additives"

- Natural "Alloy" to value existing PA6 and PP contamination as "LTHA Additives"

PCR nature : High productivity

- Improved flow and fast crystallization

One formulation to serve broader temperature range

- BIC temperature range from 170C to 230C

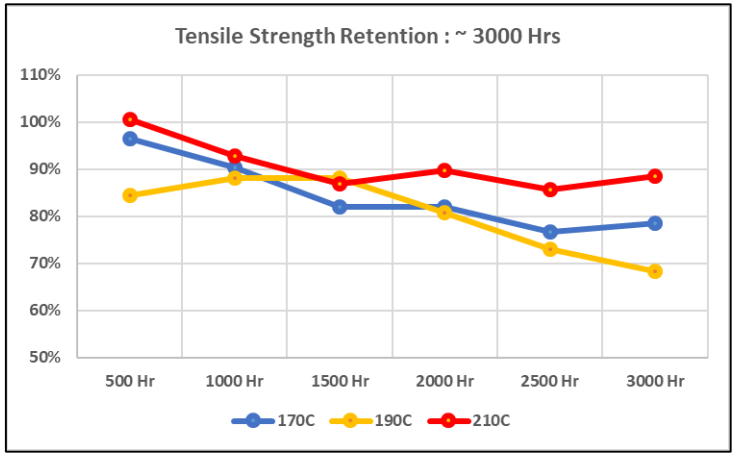
BIC $Price/Performance

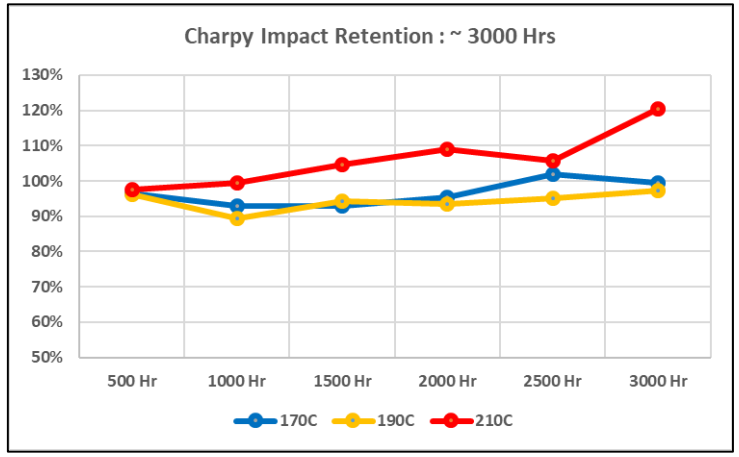
- Lowest formulation cost to offer BIC "$Price/Performance" value

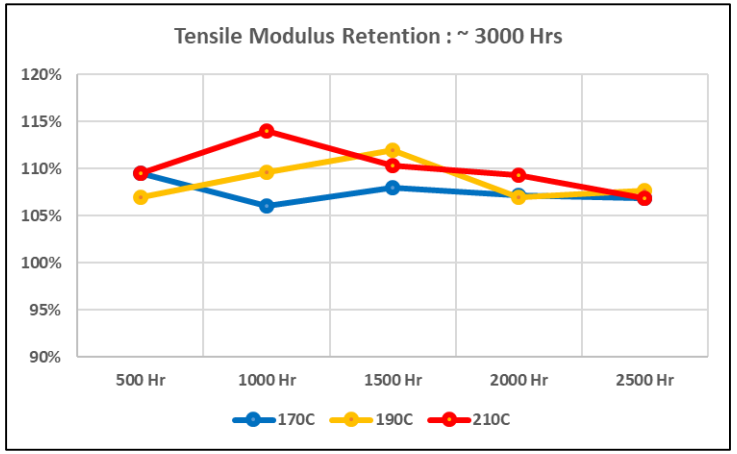
Existing thermal history

- Prompt activation for high heat resistance

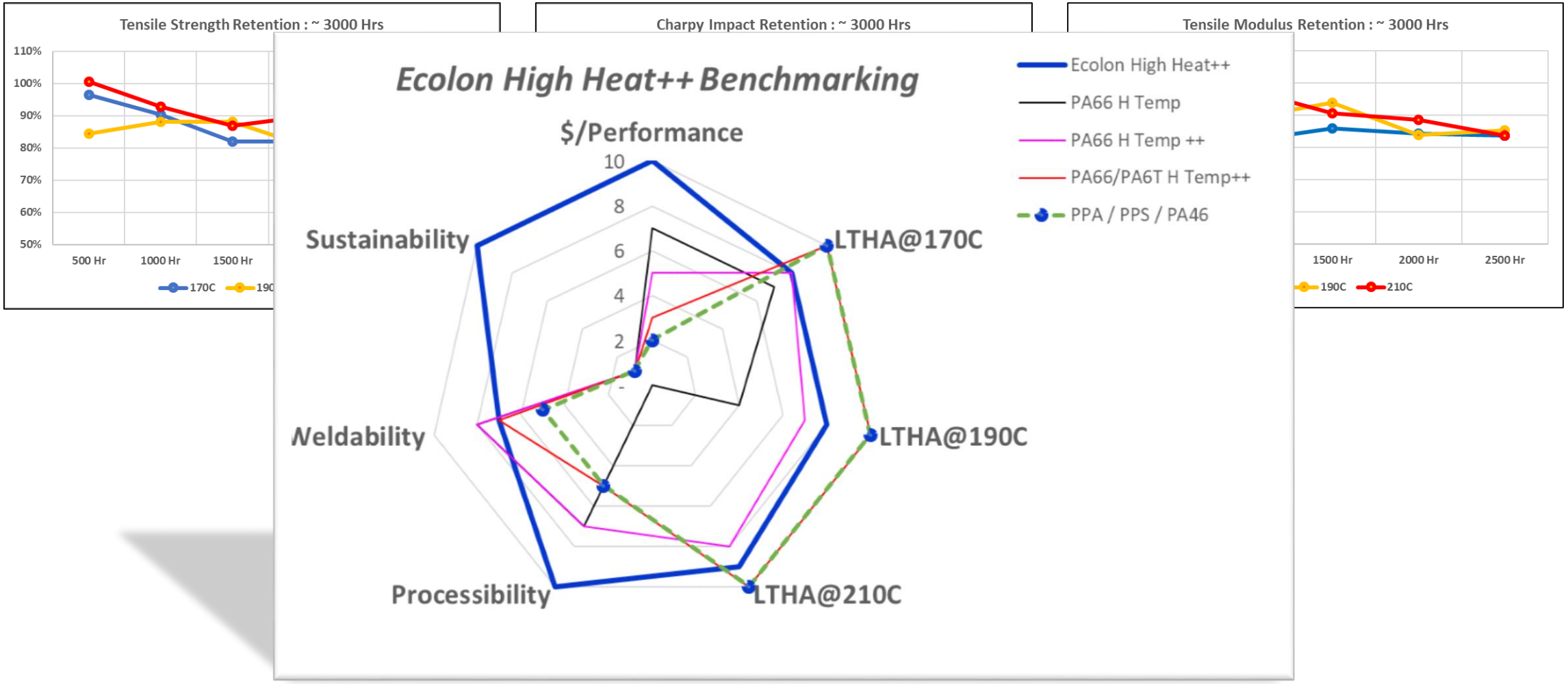
Ecolon High Heat PA66++







Ecolon High Heat PA66++



06 Introduction to PRET/Wellman

Wellman History

2018 Opened European Office

2015 Wellman acquisition by PRET

2013 Win SAE & SPE Awards

2010 1st CAM Cover using 100% PCR Material.

1996 1st Auto Application In a PCR Material.

1990 1st development of PCR Resins from carpet

1968 Engineering Resins Division Forms

1965 Nylon Fiber from PIR Materials

1927 Wool Combing In Massachusetts

2014 Chonqing Plant

2012 Jiaxing Plant

2011 Jinshan Plant

2009 Listed in the China Stock Exchange

2003 Shanghai Headquarters

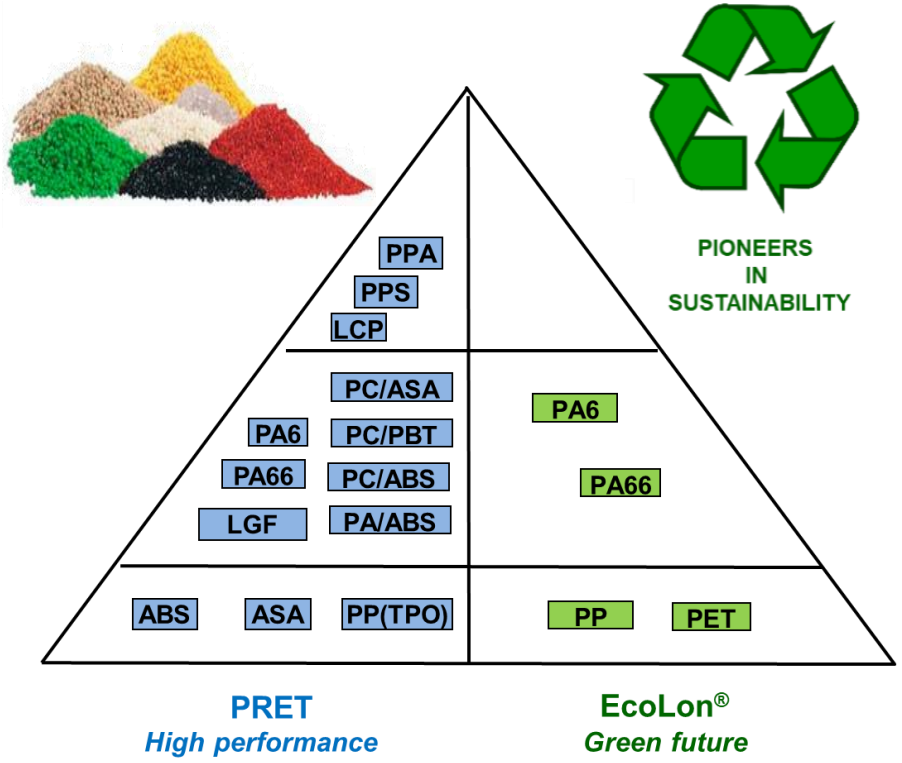
1998 Initial Plant

1993 PRET Chemical R&D Institute Formed

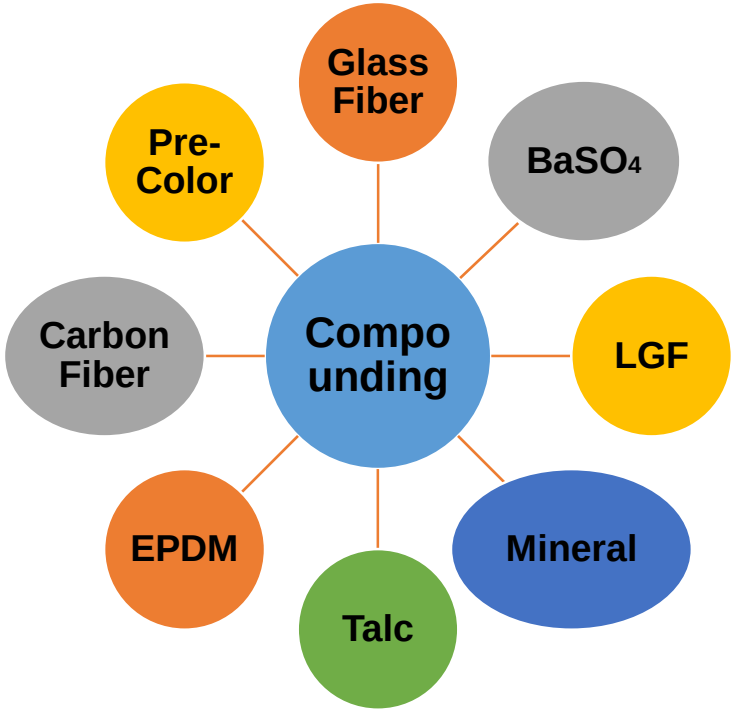
PIONEERS IN SUSTAINABILITY

Resin Choices Now Nearly Limitless

Products Available



Compounding



Environmental Contribution by EcoLon® Resins

Conservative estimate of 315,000,000 lbs of EcoLon® used by Ford equates to…

Over 85,000 US homes powered for 1 year

Over 1.5 BILLION square feet of carpet out of landfills

Equivalent of 2321 Times the MIS Speedway

Over 21,000,000 Gallons of oil preserved