

#### Cyclic Olefin Copolymer (COC) – Valuable Polymeric Modifier for Recyclable & Sustainable PE Packaging Applications

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### **TOPAS® COC**

#### Outline



- What is COC?
- **COC Compatibility with PE**
- Unmet Needs for Recyclable & Sustainable PE Packaging:
  - Stiffness Enhancement
  - Mechanical Stability at Elevated Temperatures
- Film Structure Guidelines
- Testing Recyclability:
  - **Trex Criteria & Results**
  - APR Recycling Study: COC-HDPE Films for Stand-Up Pouch (SUP)
- Conclusions

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### What is COC? COC Compatibility with PE



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COC molecule is a chain of small CH<sub>2</sub>-CH<sub>2</sub> links randomly interspersed with large bridged ring elements

It cannot fold up to make a regular structure, i.e., a crystallite



COC has no crystalline melting point, but only a glass transition temperature,  $T_g$ , at which the polymer goes from "glassy" to "rubbery" behavior

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Cyclic Olefin Copolymer – Synthesis & Structure





- Readily available raw materials
- Highly efficient catalyst
  - Low usage
  - Catalyst removed as part of process
  - High purity product
- Transparent
  - Rigid bridged-ring structure prevents crystallization

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### COC Compatibility with PE

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	Cyclic Olefin Copolymer (COC)	Linear Low Density (LLDPE)
1st Co-monomer	Ethylene	Ethylene
2nd Co-monomer	Norbornene	Alpha Olefins (Butene, Hexene, Octene)
Co-monomer Structure	Cyclic	Linear
Polymer Structure	Linear	Linear
Morphology	Amorphous	Semi-crystalline
Catalysts	Metallocene	Metallocene, Single-Site, Ziegler-Natta
Thermal Transition: Glass Transition Temp. (°C) Melting Point (°C)	68 - 180 	 120 - 127
Distortion Temperature: Vicat (°C) HDT (°C; 66 psi, 0.46 MPa) HDT (°C: 264 psi, 1.8 MPa)	68 - 178 62 - 168 57 - 151	90 - 120 58 - 60 38 - 40

**COC & LLDPE share similar chemical features.** 

**Consequently, COC is compatible with PE!** 

**COC** molecular structure enables higher temperature resistance.



### Unmet Needs for Recyclable & Sustainable PE Packaging: Stiffness Enhancement



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### Stiffness Enhancement





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#### Stiffness Enhancement Illustrated: Formed Cavities: COC & Octene LLDPE





0 10 15 20 30 % COC Incremental addition of TOPAS<sup>®</sup> 8007 into monolayer LLDPE clearly shows progressive improvement in cavity appearance.

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### Unmet Needs for Recyclable & Sustainable PE Packaging:

#### Mechanical Stability at Elevated Temperatures



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#### loss elastic modulus

#### Mechanical and Thermal Property Comparison\*\*\*





### Thermal Distortion & Transitions Temperatures: COC & PE



Polymer	Grade	Manufacture	Density (g/cc)	Melting Point	Tg (°C)	Vicat Softening	HDT (°C) [66	HDT (°C) [264
Test			ASTM D792 /			ASTM D1525	ASTM D648	ΔSTM D648
Method			D1505 ISO 1183	D3418	ISO 11357	ISO 306	ISO 75	ISO 75
	Dowlex 2045	Dow Chemical	0.920	122		108		
	Dowlex 2064G	Dow Chemical	0.935	125		119		
	Dowley 2032	Dow Chemical	0.926	124		109		
LLDPE	Petrothene GA635962	LyondellBasell	0.935				57	39
LDPE	Agility 1022	Dow Chemical	0.921	109		91		
LDPE	LDPE 4010	Dow Chemical	0.917	105		89		
HDPE	Alathon H4250	LyondellBasell	0.942	124		116	60	
HDPE	Alathon H5618	LyondellBasell	0.956	130		125	73	
HDPE	HD 6601.29	ExxonMobil	0.948	130			69	42
HDPE	HD 6719	ExxonMobil	0.952	131			73	46
СОС	TOPAS 9506	Polyplastics	1.02		65	68	62	58
СОС	TOPAS 8007	Polyplastics	1.02		78	79	72	66
COC	TOPAS 7010	Polyplastics	1.02		110	*108	*103	*92
сос	<b>TOPAS 5013</b>	Polyplastics	1.02		134	134	126	114
сос	TOPAS 6013	Polyplastics	1.02		138	135	130	117
сос	TOPAS 6015	Polyplastics	1.02		158	155	150	133
СОС	<b>TOPAS 6017</b>	Polyplastics	1.02		178	178	170	151
Sources:	ces: Company Datasheets & www.ulprospector.com: *estimated value							

HDT measures resistance to deformation at elevated temperatures under load. COC can minimize distortion of PE exposed to thermal & mechanical stress!

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2.7 mil Three-Layer Blown Film (TOPAS-PE Blend / PE / TOPAS-PE Blend)

TOPAS 6013F-04 (T<sub>g</sub> 138°C) dramatically increases PE modulus at hot fill temperatures

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### Seal Initiation vs. Modulus

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COC significantly improves film modulus without compromising seal initiation temperature.



#### Film Structure Guidelines



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### PE-COC Guideline Structures for Recyclable\* ALL PE Films



#### **Polyolefin Materials**

■ COC, LLDPE (any comonomer), HDPE, LDPE (sparingly)

#### Monolayer

- 20-40% COC (inefficient, not recommended)
- Multiple layers enable efficient distribution of COC in the film, tailored mechanical properties, and lower material cost.

#### Three Layer: Ratio: 20-60-20 or 15-70-15

- A: 30-70% COC: outer skin layer, temperature resistance
- B: 0-20% COC: core layer, deformation stability, stiffness, reclaim
- C: 10-15% COC: sealant layer, seal strength

#### Five Layer: Ratio: 15-15-40-15-15 or 10-20-40-20-10

- A: 30-70% COC: outer skin layer, temperature resistance
- B: 0-20% COC: outer tie layer, deformation stability, stiffness, reclaim
- C: 0-30% COC: core layer, deformation stability, stiffness, reclaim
- D: 0-20% COC: inner tie layer, deformation stability, stiffness, reclaim
- E: 10-15% COC: sealant layer, seal strength

\* These are all readily reprocessible in-house; as post-consumer 'recyclability' definitions and testing are continually evolving, please ensure any structure conforms to recycling regulations and guidelines for the region where product is to be sold and used





### Recycle Testing Results: Trex Association of Plastics Recyclers (APR)



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TOPAS Sample #	Description (monolayer)	PE MFR (dg/min) *(190°C; 2.16kg)	COC MFR (dg/min) (190°C; 2.16kg)	COC Tg (°C)	Trex Sample #	Melt Index (dg/min)	Ash (%)	DSC Peak Temperature (°C)	Indicative Structure	Acceptance
F06-35-1	Exxon HD7925 (HDPE)	2.5			19-0137	13.519	0.00	138	HDPE Blend	Yes
F06-35-2	HD7925 + 20% 8007F-400	2.5	1.8	78	19-0139	2.4405	0.0071	139	HDPE Blend	Yes
F06-49-1	Exceed 1018CA (LLDPE)	1.0			19-0140	0.9601	0.0008	121	LDPE/LLDPE Blend	Yes
F07-12-5	90% 1018 CA + 10% 8007 F04	1.0	1.8	78	19-0138	1.004	0.0031	121	LDPE/LLDPE Blend	Yes
F07-12-6	80% 1018CA + 20% 8007 F04	1.0	1.8	78	19-0141	1.0189	0.0021	120	LDPE/LLDPE Blend	Yes
F07-12-7	70% 1018CA + 30% 8007 F04	*1.0	1.8	78	19-0142	1.0718	0.0195	122	LDPE/LLDPE Blend	Yes
F12-52-20	95% FP120C + 5% 5013F-04	*1.0	<0.1	134	19-0143	0.9197	0.039	119	LDPE/LLDPE Blend	Yes
F12-52-21	90% FP120C + 10% 5013F-04	*1.0	<0.1	134	19-0144	0.8151	0.0009	124	LD/HDPE Blend	Yes
F12-52-22	80% FP120C + 20% 5013F-04	*1.0	<0.1	134	19-0145	0.7741	0.0005	123	LD/HDPE Blend	Yes

All COC containing film samples are recyclable according to Trex Protocols. DSC clearly distinguished HDPE crystalline melting point from LLDPE, LDPE or PP.

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#### APR PE Film Critical Guidance (FPE-CG-01)





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### Polyolefin Control & Innovation SUP Films

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5-Layer Polyolefin Control Film				5-Layer Polyolefin-COC Innovaton Film				
	Layer	Material	Resin		Layer	Material	Resin	
	Thickness	Percentage	Туре		Thickness	Percentage	Туре	
Layer	(%)	in Layer		Layer	(%)	in Layer		
A (Outer)	10	85	LLDPE	A (Outer)	10	35	COC: Tg = 110°C	
		15	LDPE			35	COC: Tg = 138°C	
						30	LLDPE	
B (Outer Tie)	20	100	HDPE	B (Outer Tie)	20	85	LLDPE	
						15	COC: Tg = 78°C	
C (Core)	40	85	LLDPE	C (Core)	40	100	HDPE	
		15	LDPE					
D (Inner Tie)	20	100	HDPE	D (Inner Tie)	20	80	LLDPE	
						20	COC: Tg = 78°C	
E (Sealant)	10	80	LLDPE	E (Sealant)	10	85	LLDPE	
		20	LDPE			15	COC: Tg = 65°C	
Total:	100			Total:	100			

Innovation SUP film uses total of 15.5% COC, distributed as: 3.5% Tg=138°C, 3.5% Tg=110°C, 7.0% Tg=78°C & 1.5% Tg=65°C.

#### APR Film Test Results: Bulk Density





No detrimental influence from COC on film bulk density.

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# APR Film Test Results: Extrusion & Pellets **Polyplastics**



	Extruded Pellet	Extrusion/Pellet Data					
Control	T CHICC	Variable	Control	Test 50%	Test 100%		
		Melt Temperature (°C)	220	220	221		
		Screen Pack Pressure Build (%)	-5.00%	3.60%	-2.94%		
		Density (g/cm³)	0.946	0.947	0.949		
		Melt Flow Rate (g/10min)	1.455	1.097	0.855		
		Volatiles/Moisture (%)	0.0041	0.0198	0.0145		
lest 50%		Ash Content (%)	0.41%	0.31%	0.19%		
		Bulk Density (kg/m³)	545	542	529		
	Carl Part	Primary Peak Temperature (°C)	128.63	128.16	127.35		
Test 100%		Percent Polypropylene	<1.00%	<1.00%	<1.00%		
		All films exhibit s	similar e	extrusio	n behav		

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#### **APR Film Test Results: Properties**



#### **Blown Film**



Test 50%

Control



Test 100%



Variable	Control	Test 50%	Test 100%
Process Stability	Yes	Yes	Yes
Thickness (mils)	2.0	2.0	2.1
MD Tear Strength (gf)	159.2	338.0	624.6
(Delta%)		(112.37%)	(292.39%)
TD Tear Strength (gf)	248.8	521.1	389.0
(Delta%)		(109.43%)	(56.40%)
MD Tensile Strength (psi)	3055	3421	3253
(Delta%)		(11.97%)	(6.49%)
TD Tensile Strength (psi)	2481	3148	3303
(Delta%)		(26.90%)	(33.11%)
MD Elongation at Yield (%)	40.798	41.645	57.879
(Delta%)		(2.08%)	(41.87%)
TD Elongation at Yield (%)	8.057	44.450	55.332
(Delta%)		(451.70%)	(586.76%)
Dart Impact Strength (g)	158	200	698
(Delta%)		(26.84%)	(342.86%)
F.A.R	1	0	0

**COC improved all mechanical properties!** 

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#### **Blown Film Data**



#### **Conclusions**



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- Unique among polyolefins, HDT and Modulus of COC perform like temperature-resistant engineering thermoplastics such as PA & PET.
- HDT better explains how polyolefin materials respond to thermal deformation under load than Vicat.
- **COC** can minimize distortion of PE exposed to thermal & mechanical stress!
- COC demonstrated recyclable under Trex protocols.
- Stand-Up Pouch (SUP) film with 15% COC satisfied APR PE Film and Flexible Packaging protocols (FPE-CG-01).
  - Critical Guidance Recognition letter is in The APR Design<sup>®</sup> Guide for Plastics Recyclability.
- In Europe, COC has been certified as recyclable in both PE and PP films by Institut cyclos-HTP.
- Shrink sleeves with COC have passed bottle recycling protocols in US & EU.
- Further recyclability testing is underway in multiple regions.

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