Biaxially Oriented Polyethylene (BOPE) Films Fabricated via Tenter Frame Process and Applications Thereof

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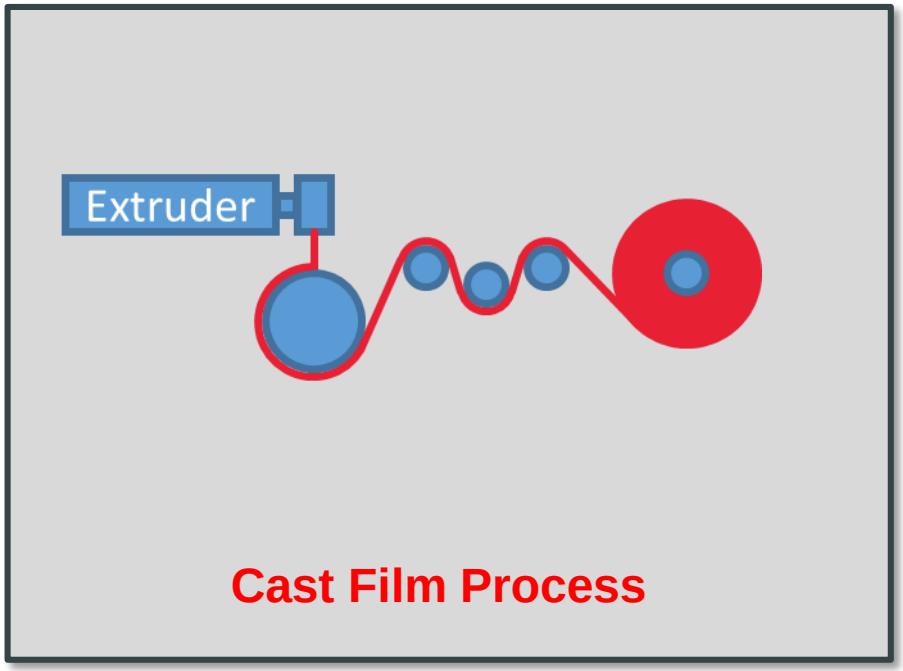
DowDuPont

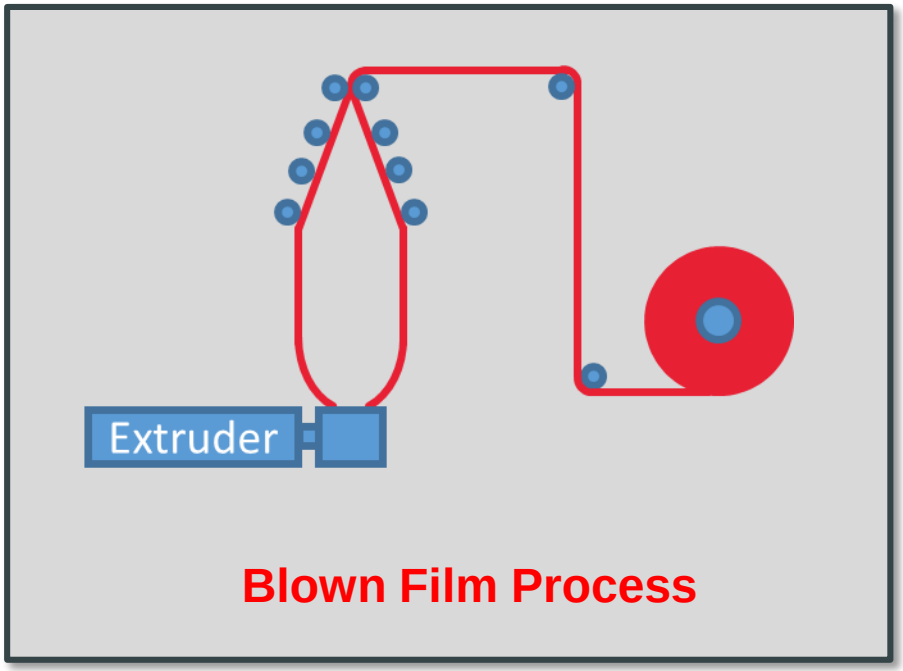
Outline

- BOPE made via tenter frame process
- Crystal orientation of BOPE films
- BOPE film properties
- BOPE applications

Conventional Fabrication Processes to Make PE Films



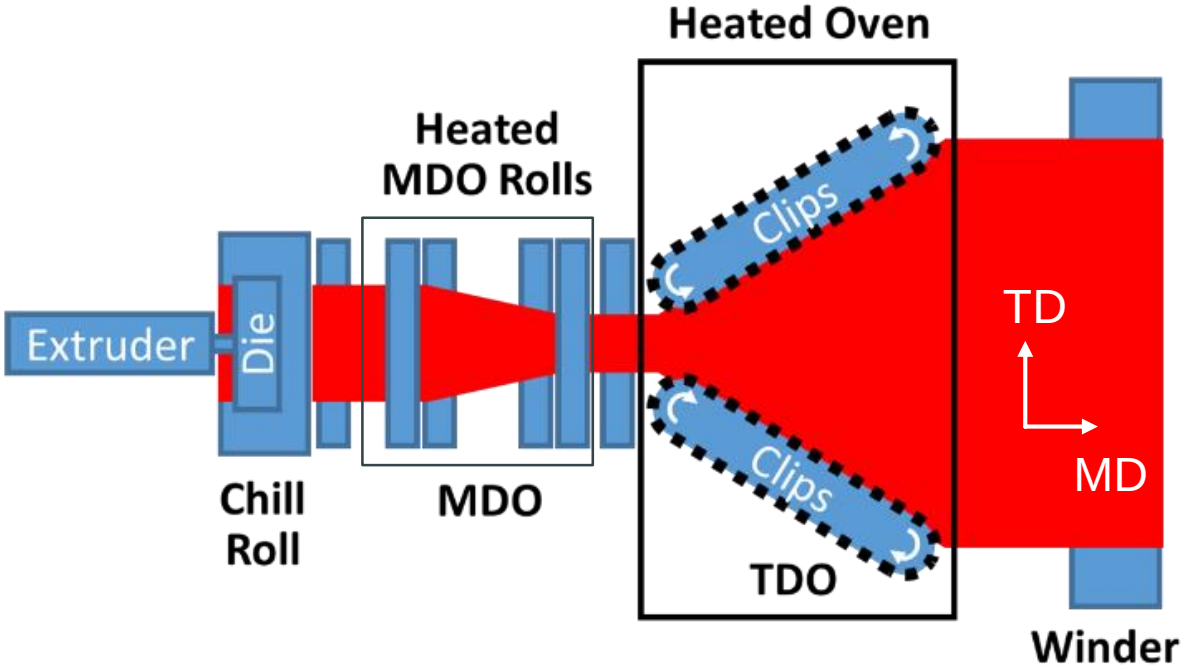
Cast Film Process



Blown Film Process

Orientation occurs in the molten state of a polymer

Tenter Frame Process

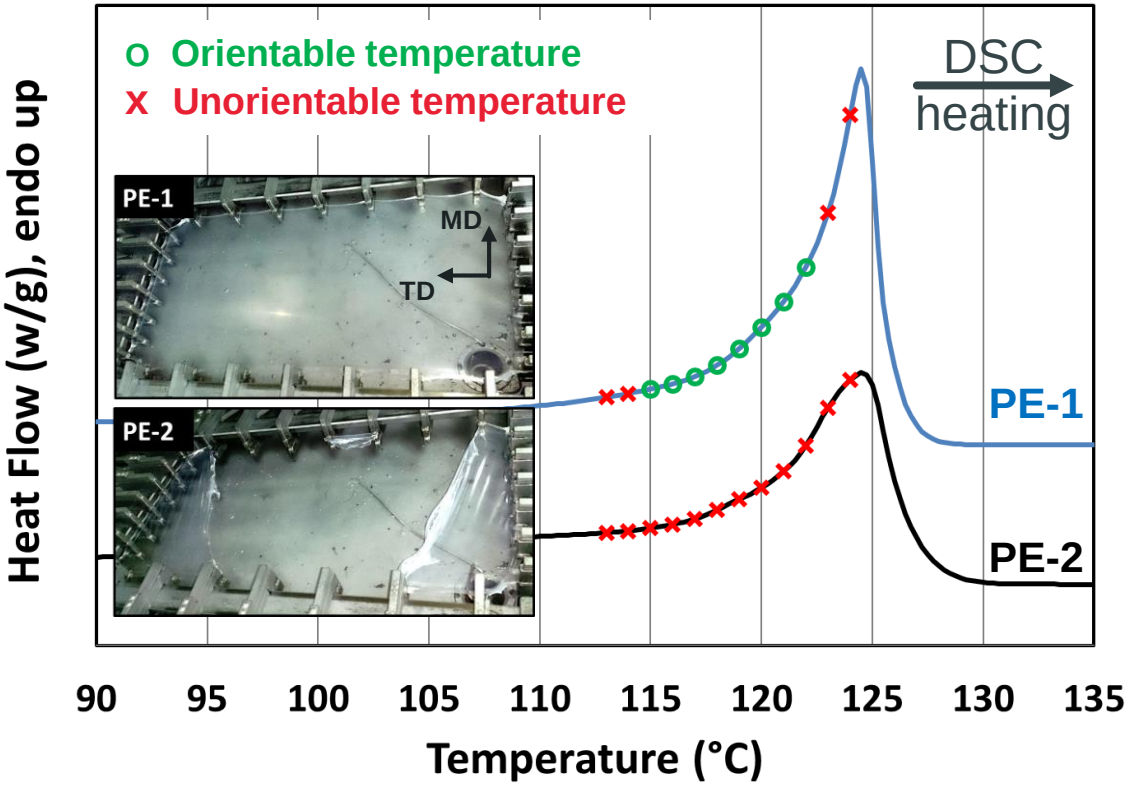


- Orientation occurs in semi-solid state
- No tenter frame line specifically designed for PE
- Typical BOPP line has 5x MDO and 9x TDO
- Conventional PE cannot be processed through BOPP line due to its poor stretchability

Selection of PE Grade for Tenter Frame Process

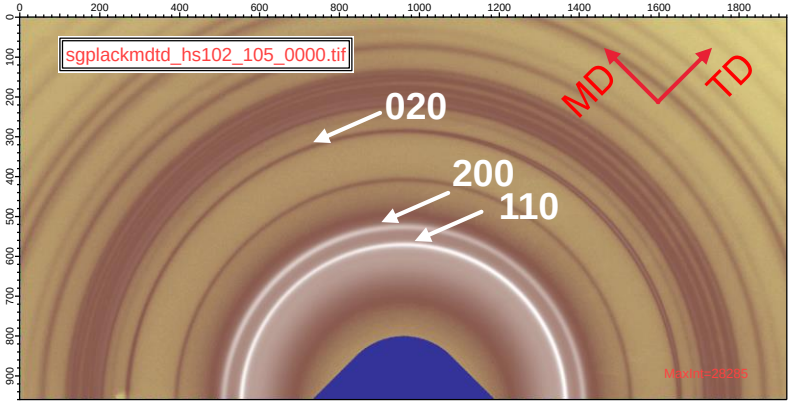
Resin	MI (g/10min)	Density (g/cc)
PE-1	1.7	0.926
PE-2	1.6	0.925

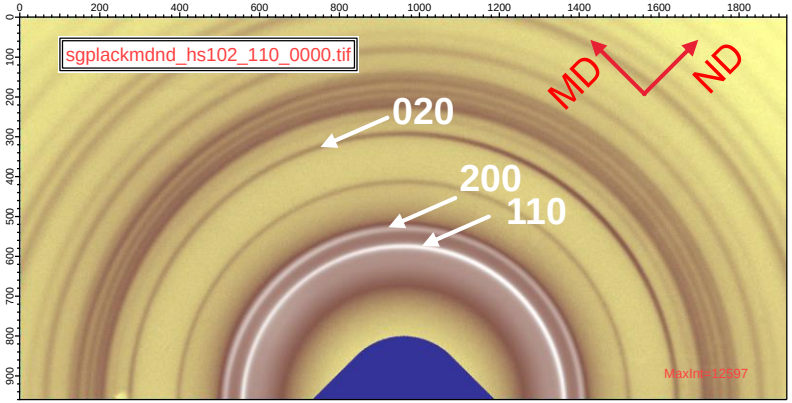
- Specific resin design is required for biaxial orientation
- Orientation temperature window determines resin processability

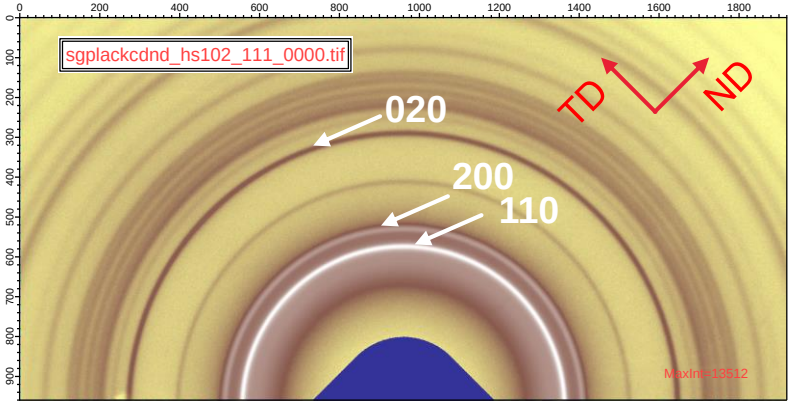


Orientation window was measured with a Brückner Karo IV lab stretcher with a 4x8 draw ratio.

Crystal Orientation of Un-oriented Sheet (WAXS)

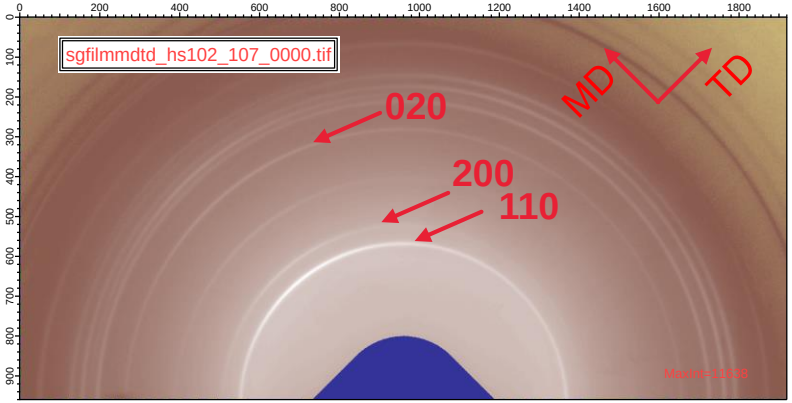


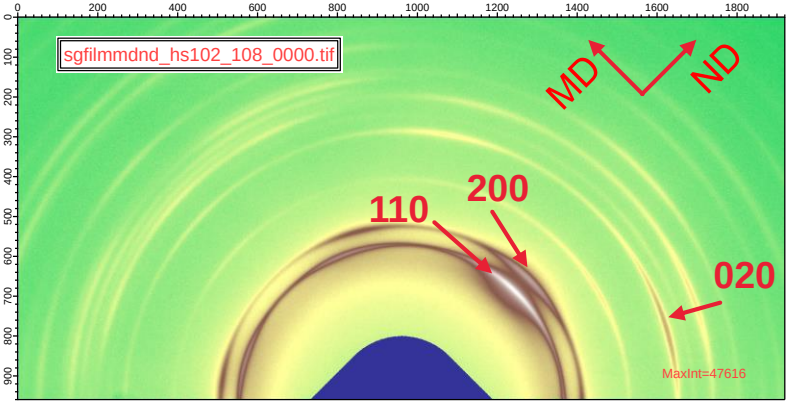


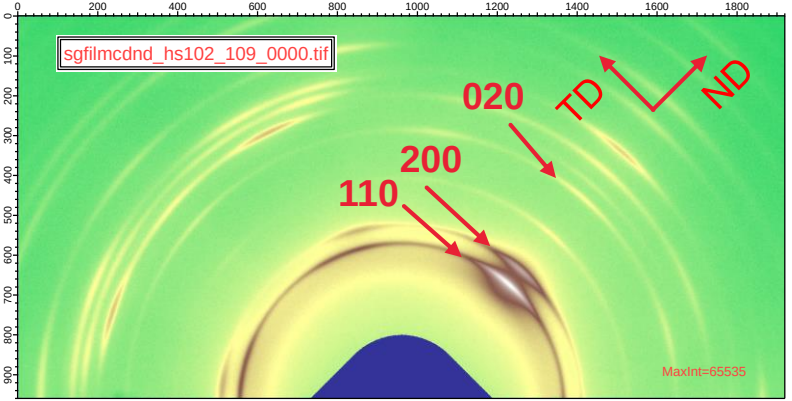


PE crystals are randomly oriented in the cast sheet before biaxial orientation

Crystal Orientation of 5x9 BOPE Film (WAXS)







Two predominant orientation modes:

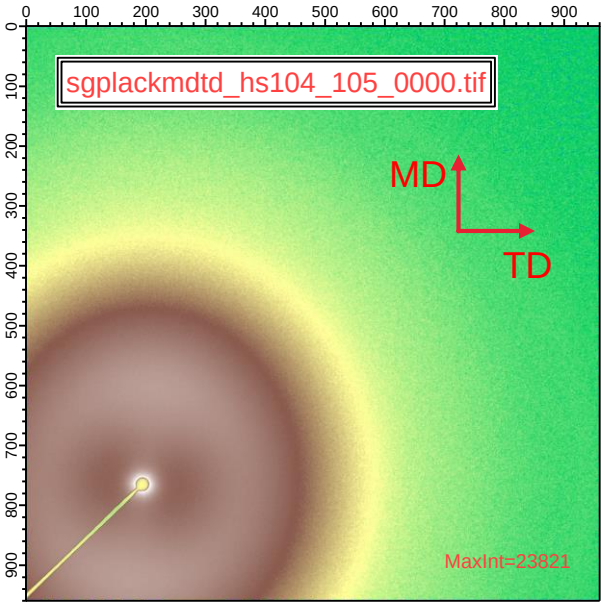
- **a-axis (200 plane) orients in ND.**
- **110 plane orients in ND.**

G.C. Adams, *J. Polym. Sci: Pt A-2*, 9, 1235 (1971).
N.S.J.A. Gerrits, R.J. Young, *J. Polym. Sci.: Pt B*, 29, 825 (1991).
A. Ajji, X. Zhang, S. Elkoun, *Polym. Eng. Sci.*, 46, 1182 (2006).

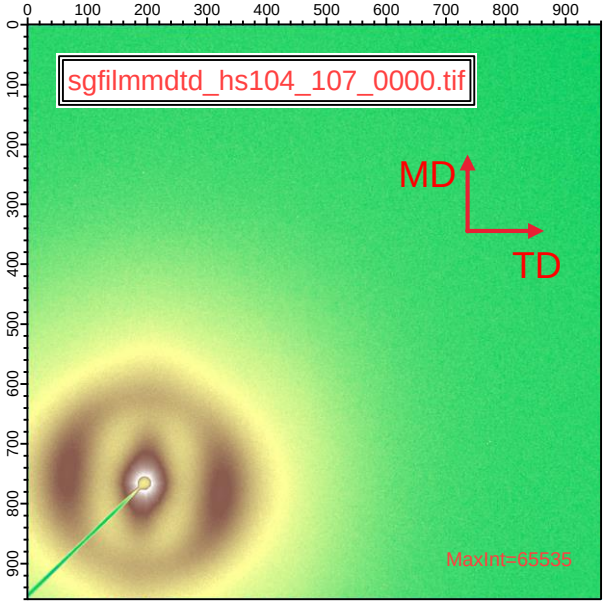
Film was made on commercial BOPP line with 5x in MD and 9x in TD

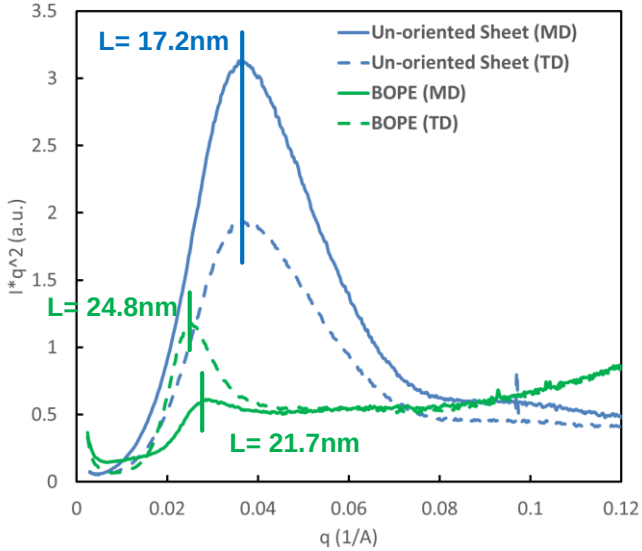
Crystal Orientation (SAXS)

Un-oriented Sheet



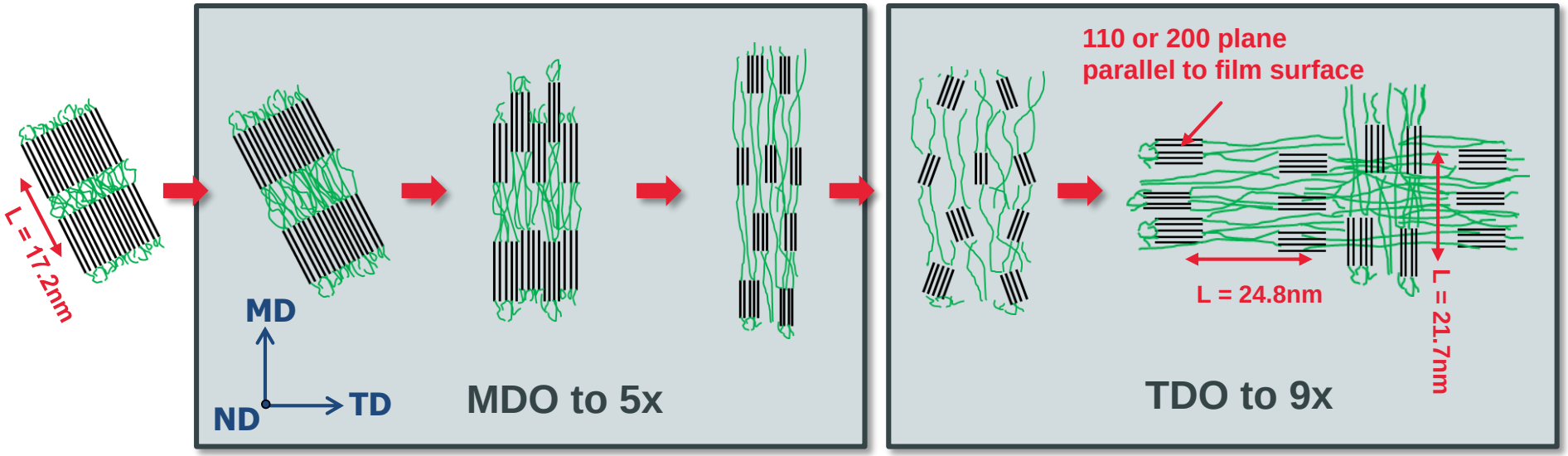
BOPE Film





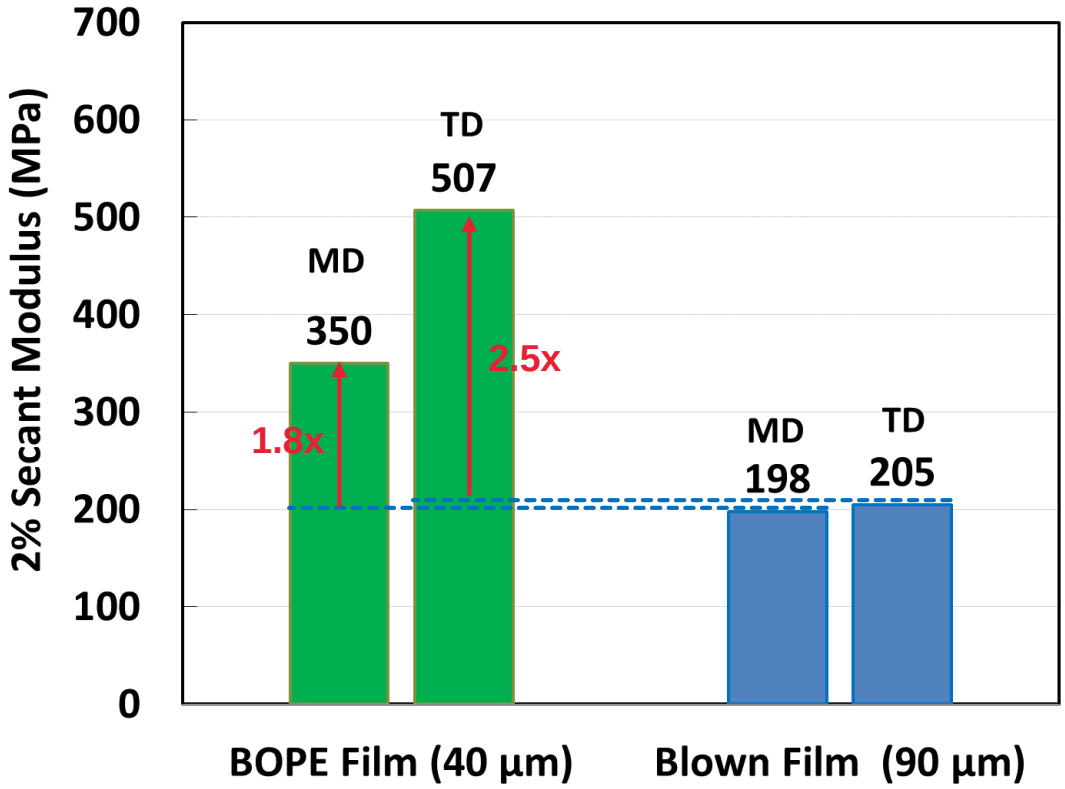
Shish-kabab structure is observed in BOPE with shish in MD and CD. Long period in TD (24.8 nm) is greater than in MD (21.7 nm)

Crystal Morphology Change during Biaxial Orientation



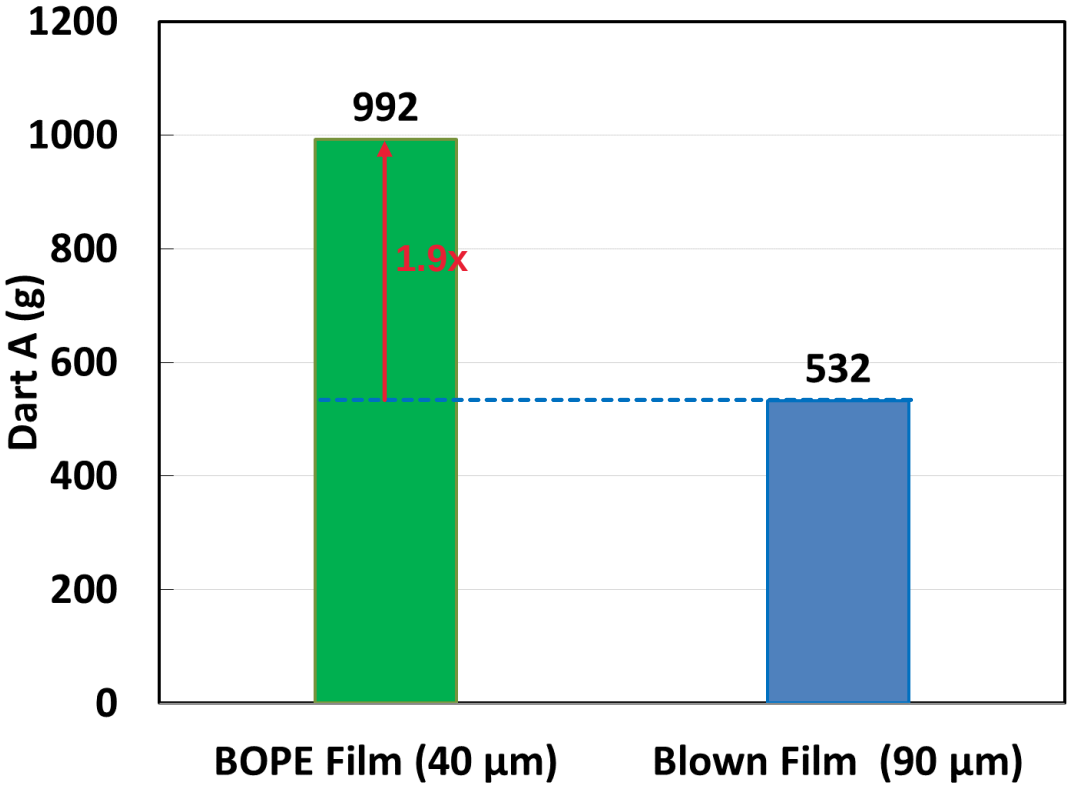
- In MDO, the crystals transform into highly oriented, fibrous structure of the shish-kebab type. The c-axis of the crystal is predominantly oriented in MD.
- In TDO, the close-packed shish–kabab fibers separate, re-oriented, and form a large population of thin fibrils with c-axis oriented in TD.
- 110 and 200 planes of the crystals are parallel to the film surface.

Modulus



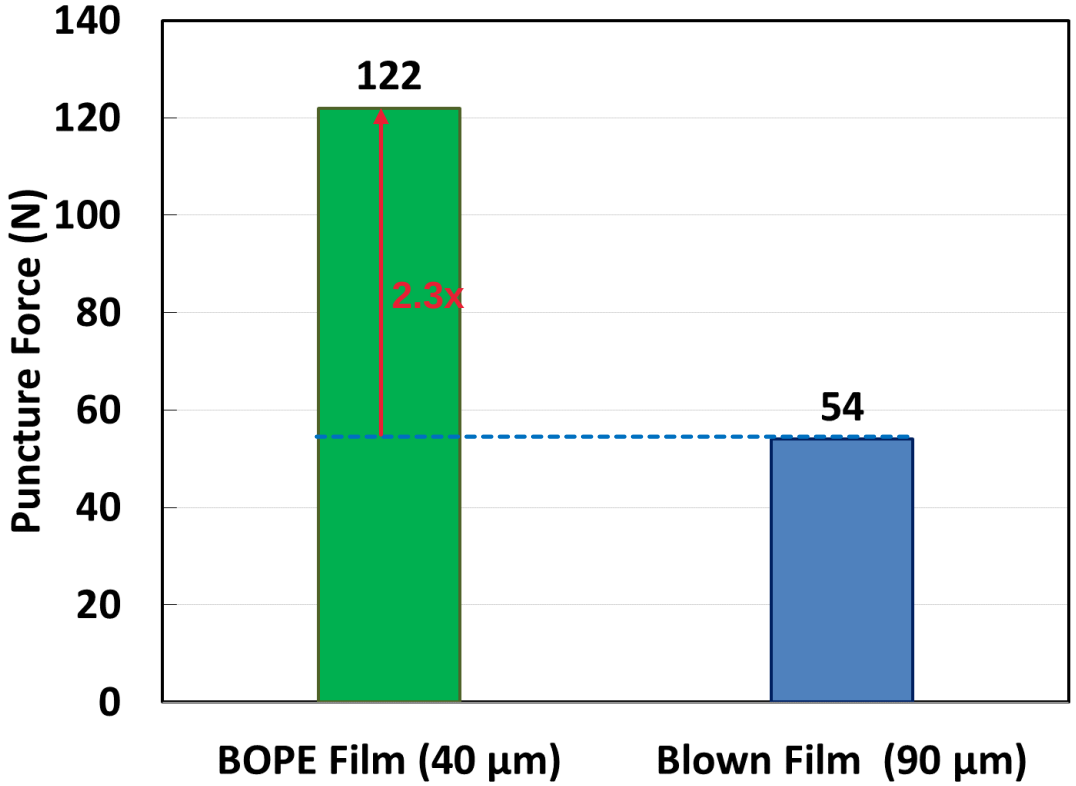
- 1.8x improvement in MD modulus and 2.5x improvement in TD modulus.
- The 40 µm BOPE film has a similar stiffness to the 90 µ m blown film, which allows downgauging.

Dart Impact



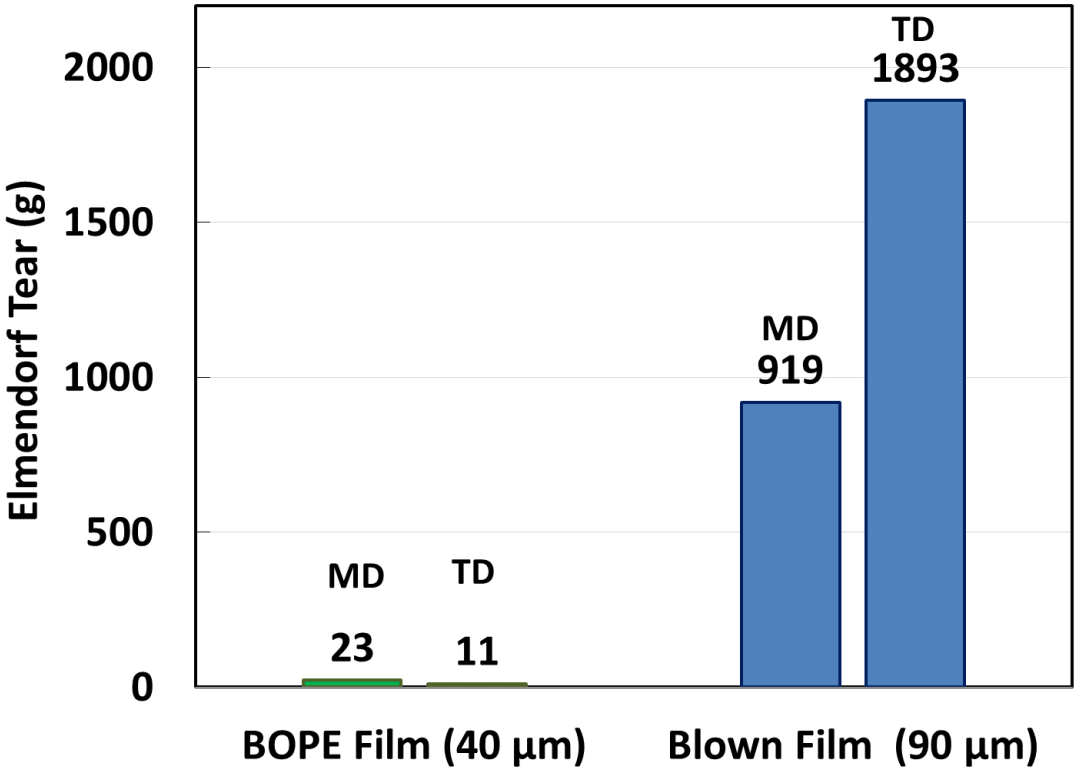
- The dart impact standard test mimics a package dropped onto the ground from a certain height
- The BOPE film shows 1.9x higher dart impact than a blown film though it is much thinner

Puncture Test

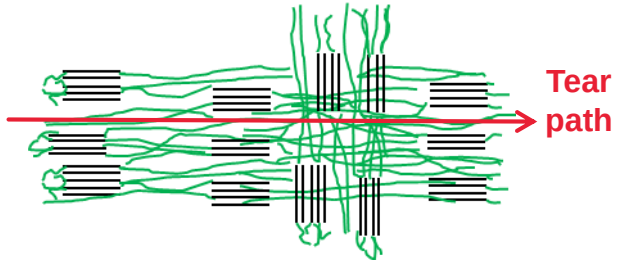


- **The puncture test measures the resistance of a packaging material to a sharp object inside or outside of the package.**
- **BOPE film shows 2.3x improvement in puncture force.**

Easy Tear



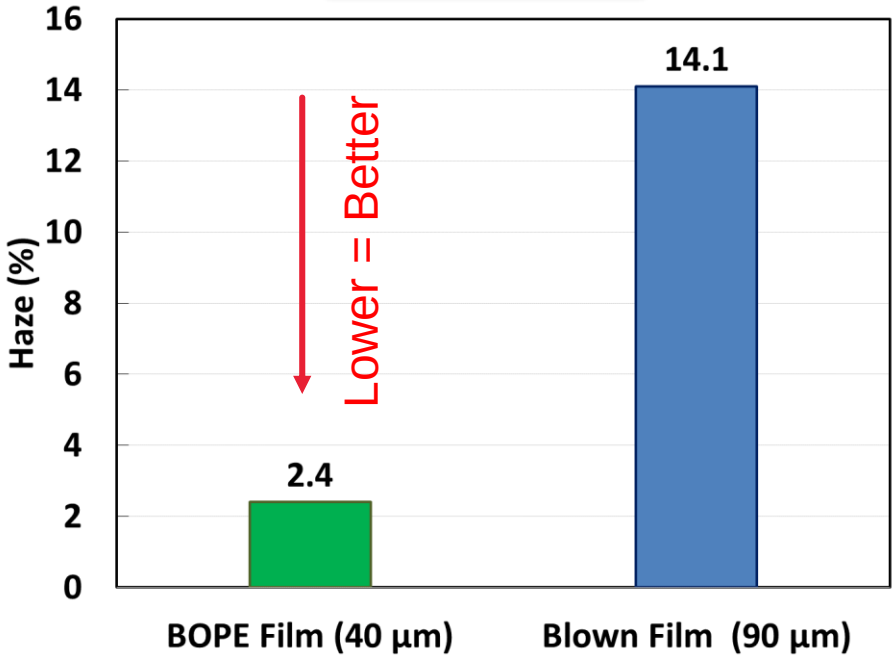
- **Lower tear of BOPE film allows consumers to open the package more easily.**
- **Lower tear of BOPE film is due to its highly oriented shish-kebab type of morphology.**



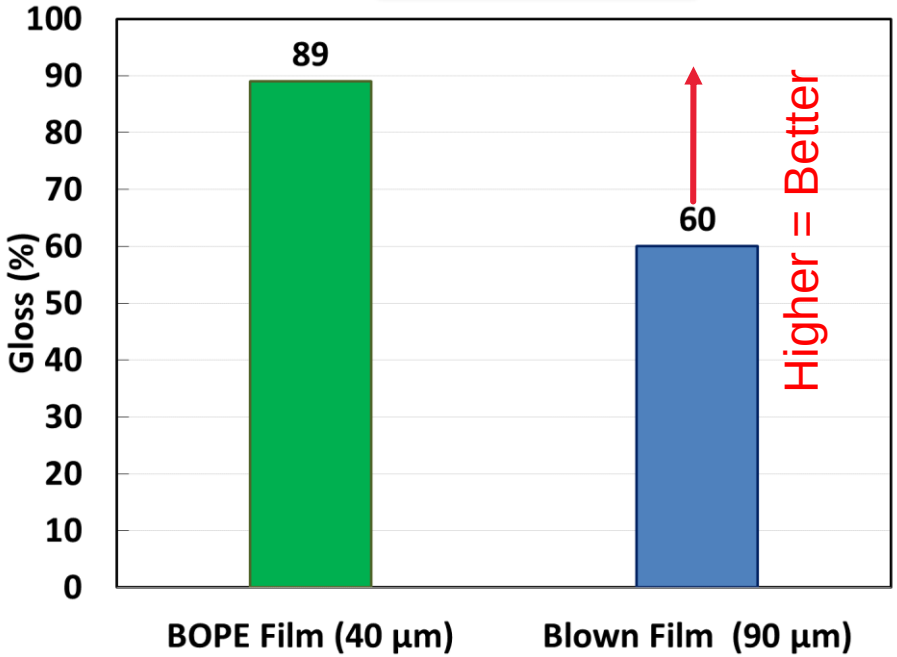
L. Liu, M. Demirors, R. Patel, B.H. Choi, K. Anderson, ANTEC, 1346 (2008).
Y.J. Lin, M. Demirors, J.P. Pan, X.B. Yun, ANTEC, 1477 (2014).

Optical Properties

Haze



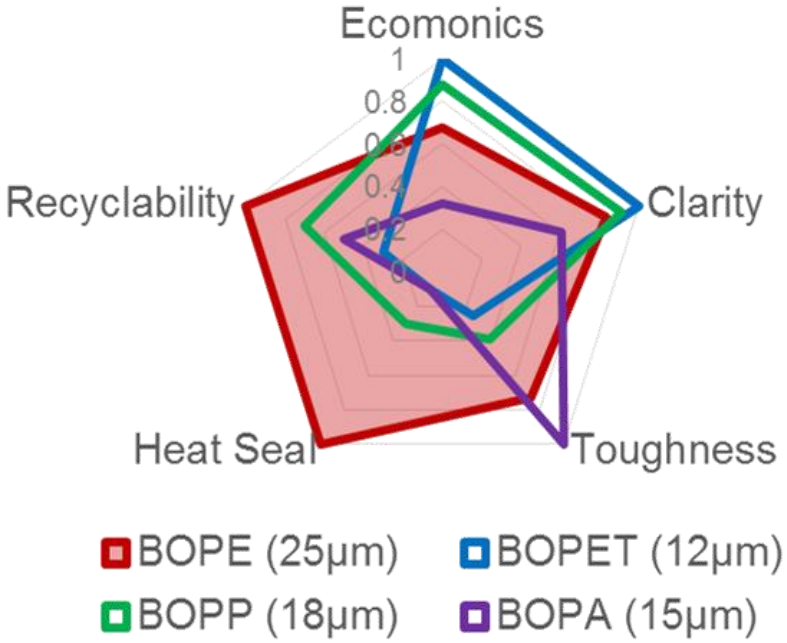
Gloss



- **Lower haze and higher gloss for BOPE film, which can be attributed to its smaller shish-kebab type of crystals and smooth surface.**

BOPE vs. Conventional Blown PE

BOPE vs. Oriented Polymers



- **Most balanced performance**
- **High clarity & high toughness**
- **Heat sealable & easy to recycle**

Replace BOPA in Liquid Stand-up Pouch (SUP)

SUP for liquid detergent

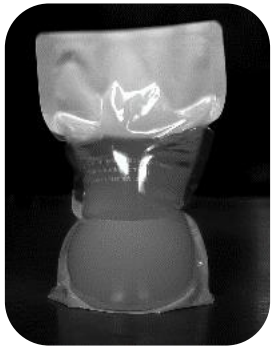
- **0.5~2L SUP with or without spout**
- **BOPET//BOPA//PE 3-ply structure**
- **BOPA in core play for toughness**
- **Drop test under various conditions**

BOPET 12μm
BOPA 15μm
PE Film 70~150μm

Incumbent structure

BOPET 12μm
TF-BOPE 25μm
PE Film 60~140μm

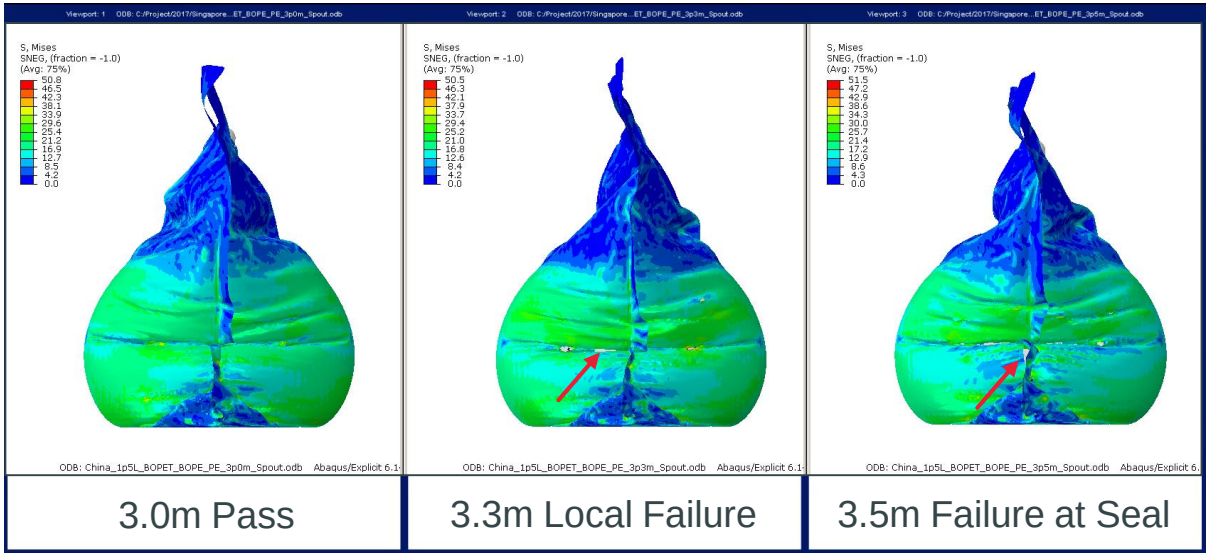
New structure



Simulation & Experiment on 1.5L TF-BOPE Based SUP

BOPET BOPA 15μm	BOPET TF-BOPE 25μm
PE Film 130μm	PE Film 120μm

Predicted critical height: 3.3~3.5m;
Experimental critical height: 3.45m



3.0m Pass	3.3m Local Failure	3.5m Failure at Seal

Drop from 3.3m - Passed

Great Success on Liquid Detergent SUP

Benefits

- ✓ Lower cost
- ✓ Excellent abuse resistance
- ✓ Good sealing performance
- ✓ Lower conversion wastage

Packaging Test	New Structure
Single Bag Drop (1.5m)	PASS
Compressive Test (150kg, 1min)	PASS
Whole Box Drop (1m) (6 Pack x 1L, Room Temp)	PASS
Whole Box Drop (1m) (6 Pack x 1L, 0° C)	PASS

Open Our Mind & Challenge Our Imagination

Printing Substrate

Frozen Packaging

All PE

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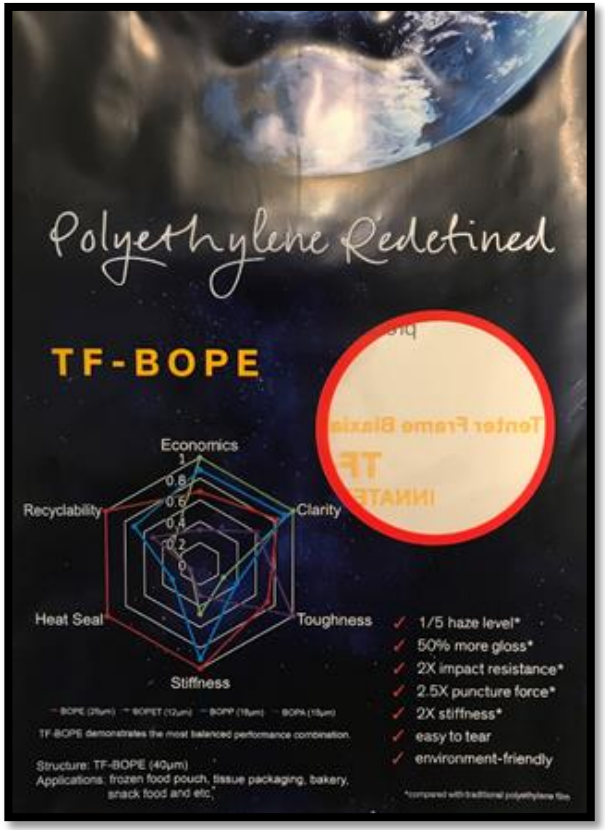

Metallized Film

Label Stock

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Thank You