



2024 FlexPack PLACE Conference

April 14-17, 2024 • San Diego, CA • Wyndham San Diego Bayside



Optimizing Extrusion Coating and Lamination Process Conditions for Adhesion of LDPE to OPE Substrate

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Outline

- Brief Introduction - Oriented Polypropylene (OPP) & Polyester (OPET) Films
- Brief Introduction - Oriented Polyethylene (OPE) Films
- **Case Study #1:** Bond Comparison of BOPET vs. OPE-Substrates in Extrusion Coating
- **Case Study #2:** Adhesion of LDPE to OPE-Substrates in Extrusion Coating – What is the mechanism?
- **Case Study #3:** Converter Processing Simulation with OPE in Extrusion Coating
- Observed Processing and Web Handling Challenges with OPE-Substrates
- Summary & Conclusions



OPP and PET Oriented Films

- Extrusion coating and lamination of BOPP and BOPET is well understood
- One of the building blocks in multilayer, multimaterial, high performance structures
- BOPP and BOPET films provide an excellent combination of the following:
 - ☐ Dimensional stability
 - ☐ Stiffness and strength
 - ☐ Gloss and clarity
 - ☐ Temperature resistance
 - ☐ Barrier properties





Typical Extrusion Laminated BOPP or BOPET Structure

- Stiff and clear BOPP or BOPET films are often reverse printed and then extrusion laminated to another BOPP, or BOPET substrate
 - ❑ Extrusion laminating equipment - designed to handle the processing of these types of films
 - ❑ Typically laminated with extrusion coating grade LDPE resins
 - ❑ Surface treatment and priming of BOPP and BOPET films - needed to achieve the desired adhesion requirements
 - ❑ BOPP and BOPET films can contain either adhesion promoting layers or heat seal layers, and are often metallized for barrier performance, as well as laminated to a 3rd substrate, such as a blown PE film
 - ❑ Coextrusion of barrier resins, such as EVOH, with LDPE can also be used to achieve barrier properties



Typical Extrusion Laminated BOPP or BOPET Structure

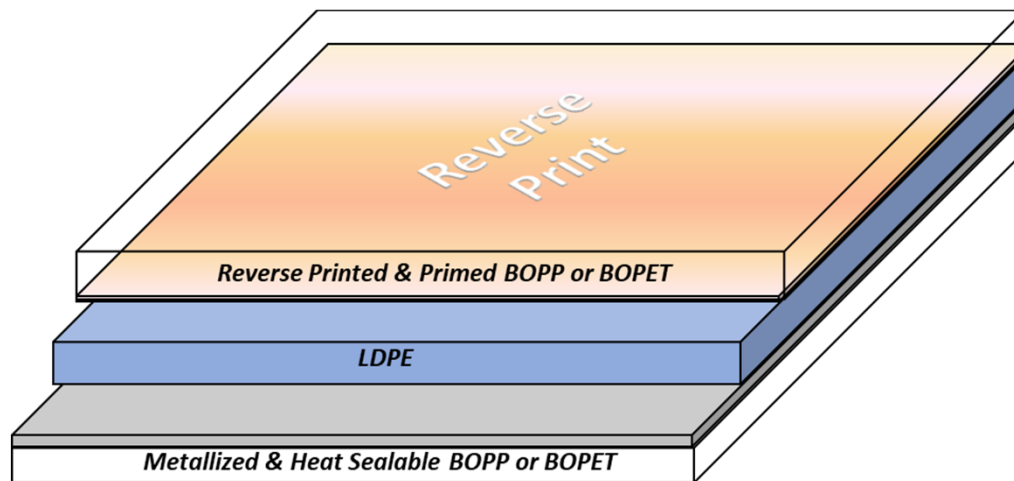


Illustration of typical BOPP or BOPET structures

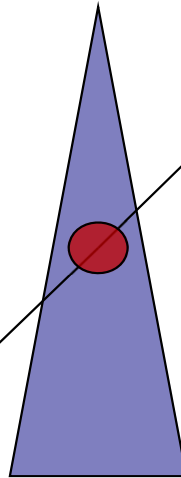
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BOPP & BOPET

**Provides excellent processing
with good physical properties
as previously noted.**



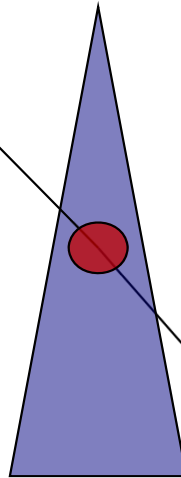
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Demand for an easier to
recycle *all-PE* structure –
mono material





Oriented Polyethylene Films

- Extrusion coating & lamination of MDO PE Films and BOPE films are not as well understood
- MD-OPE and BOPE films present the following processing challenges:

Web handling challenges

- ☐ Tension control for substrates with lower modulus (less tension)
- ☐ Shrinkage of films when treating or drying (priming)
- ☐ Metal crazing due to lower modulus and thermal stability
- ☐ Burn-through of substrate at nip during low line speeds or start-up

Adhesion

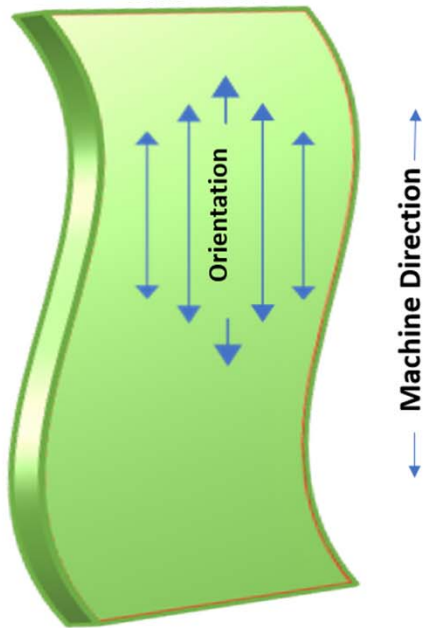
- ☐ Adhesion mechanism of polyethylene to polyethylene in extrusion coating may be different vs. processing BOPP and BOPET (e.g. optimal temperature, oxidation, and pretreatment)



Oriented Polyethylene Films

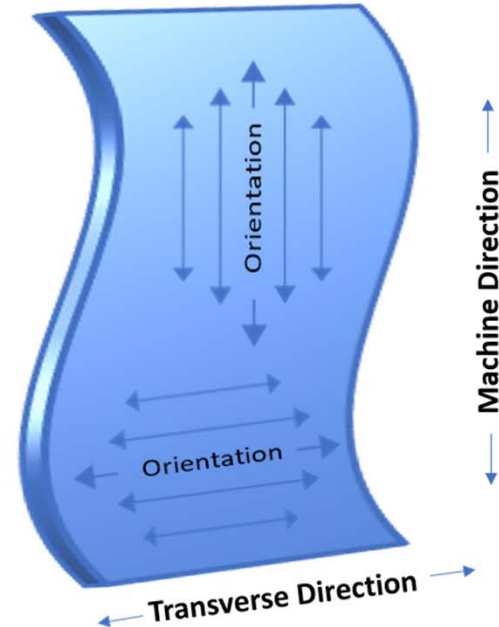
Machine Direction Orientation

MD-OPE



Biaxial Orientation

BOPE





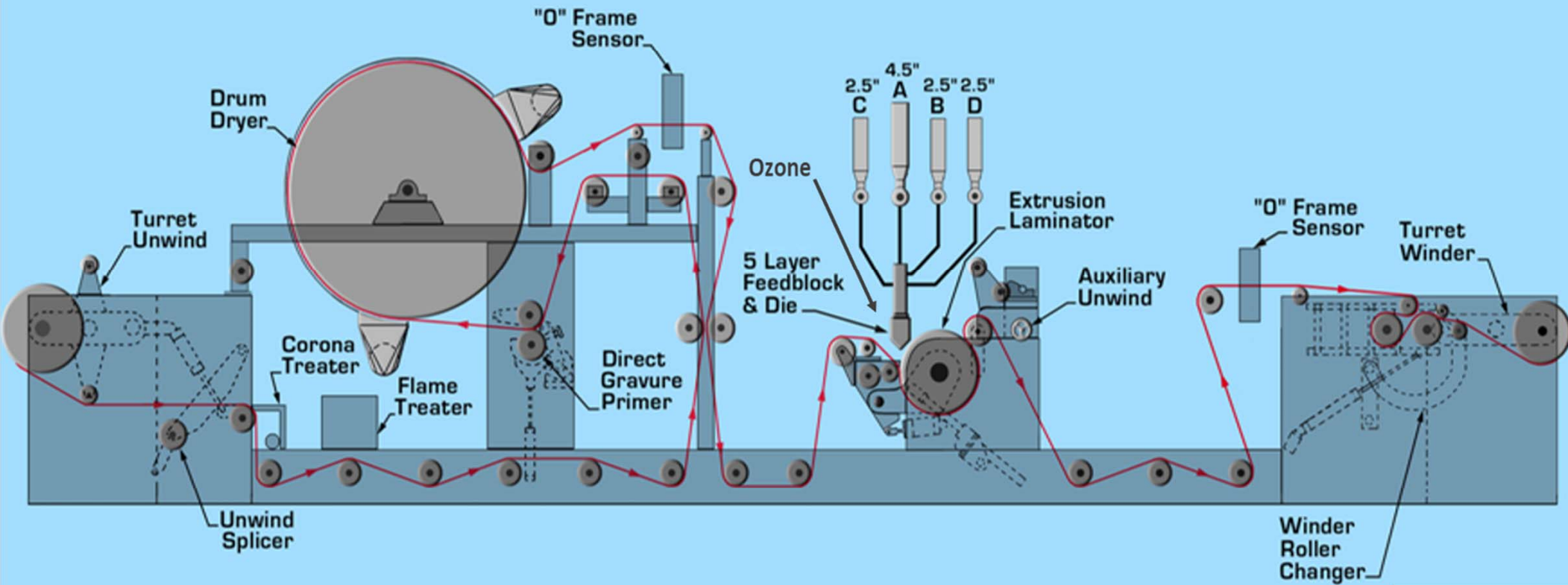
Case Studies – Processing OPET, OPE Substrates



Utilized Chevron Phillips extrusion coating pilot line to evaluate processability of OPE substrates vs. traditional BOPET substrates

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Case Study #1: Bond Comparison - BOPET vs. OPE Films

- Raw materials used in this evaluation:

Raw Material	Description
48 ga Clear BOPET Film	Clear OPET Film
100 ga Inteplast D1K Clear BOPE Film	Clear OPE Film
100 ga MDO Polyethylene Film Samples	Clear MD-OPE Film
Marlex® 1019 LDPE Resin (16 MI / 0.917 density)	LDPE



Case Study #1: Bond Comparison - BOPET vs. OPE Films

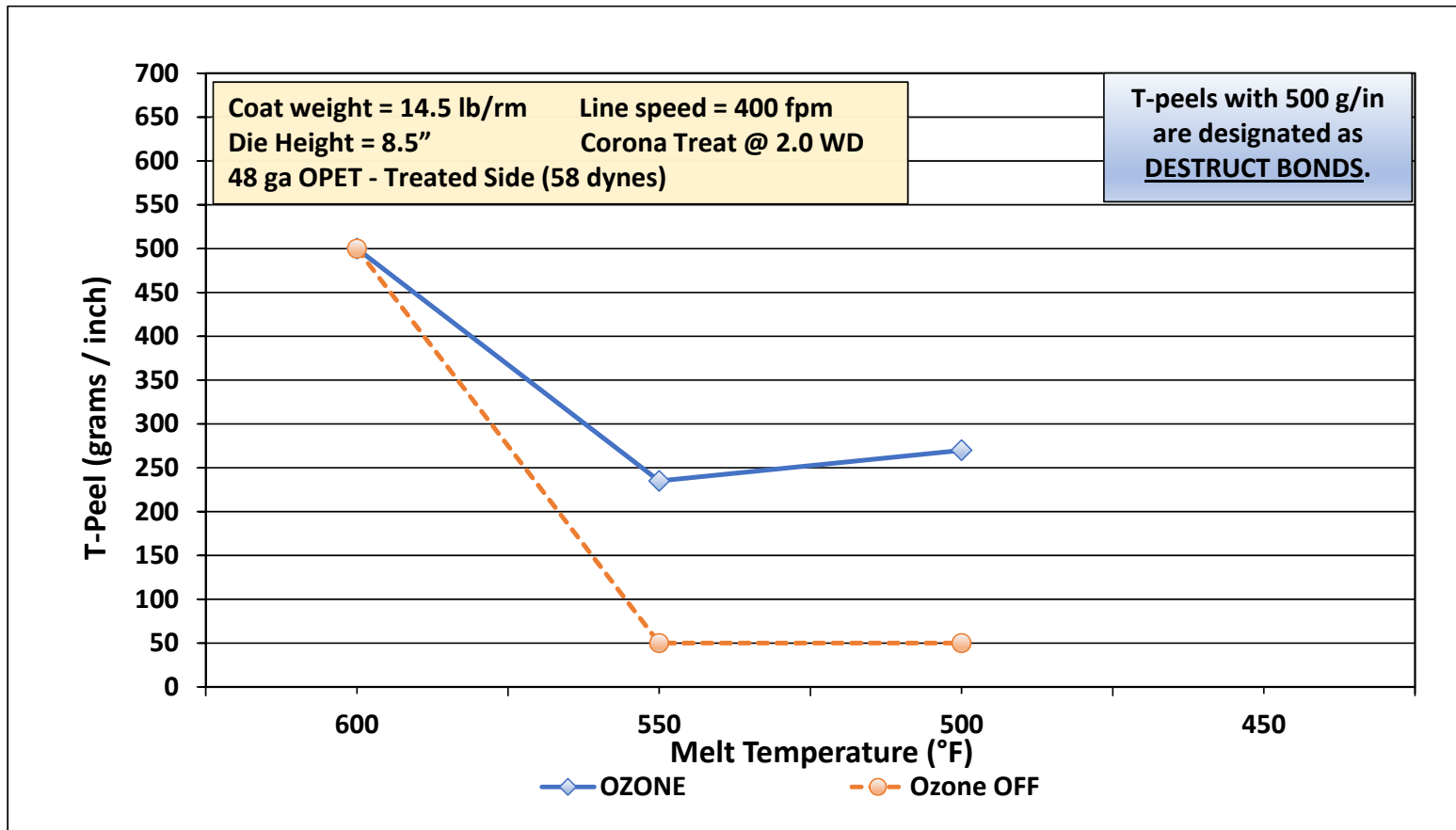
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- Clear OPET and OPE films were extrusion coated with 14.5 #/ream (1 mil) of LDPE
- Melt temperature range of 400 - 600 °F was used to evaluate bond of LDPE to the surface of clear OPET and OPE film, at defined air gap settings and line speeds
- All substrates were pretreated in-line with corona treatment @ 2.0-Watt Density (WD)
- The effect of ozonation supplied at the nip was evaluated on bond performance (500 W / 50% open)
- Other processing challenges such as neck-in of substrates, drying during priming, and burn-through of the substrates at the nip were also evaluated

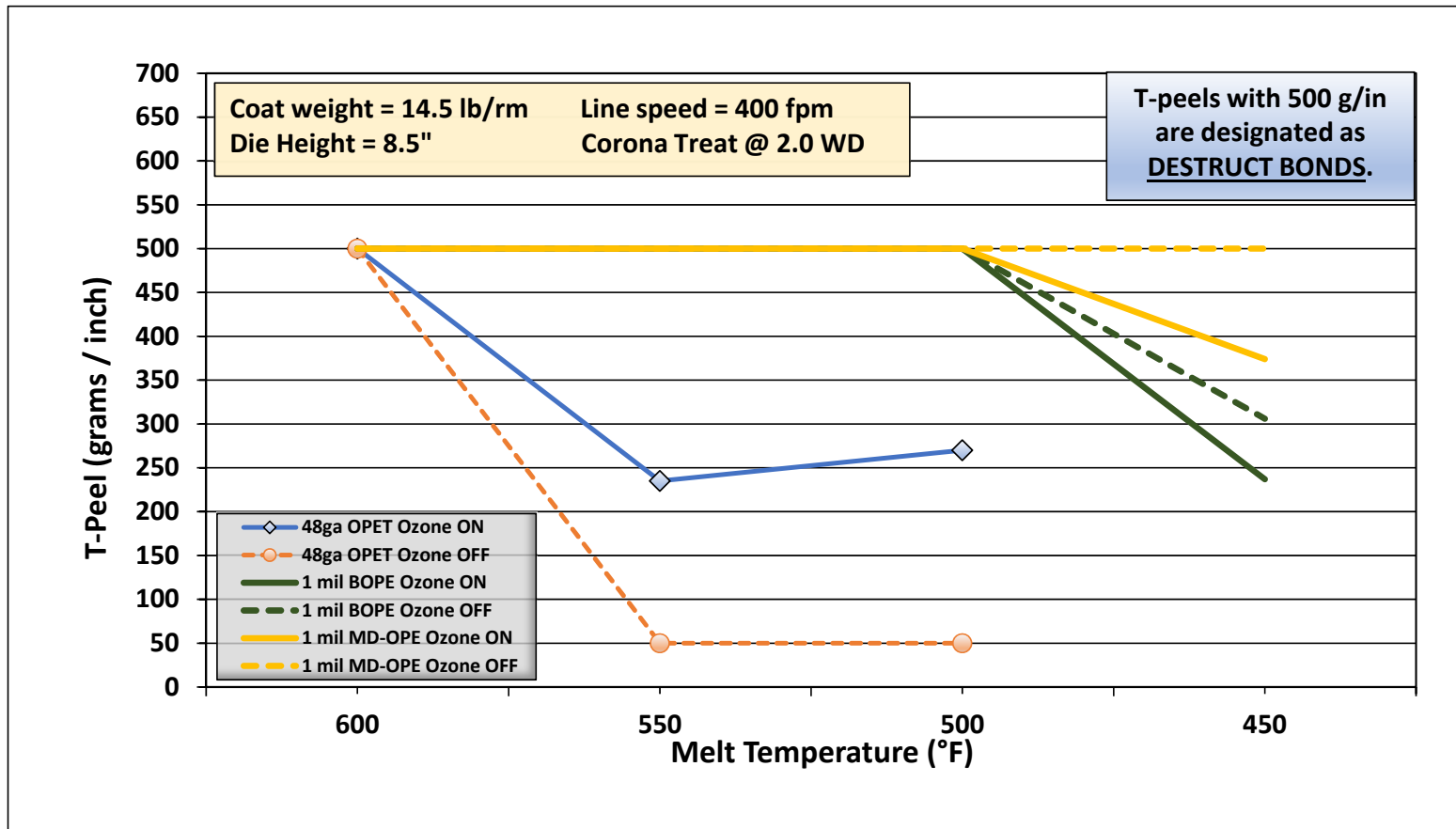


Case Study #1: OPET Substrate Bond Testing





Case Study #1: Bonds - OPET vs. BOPE, MD-OPE Substrates





Case Study #1: OPET / OPE Observations Summary

- Ozone, while improving OPET bonds to the LDPE coating, did not appear to improve bond performance with OPE at lower temperatures
- Ozone, at higher temperatures, did not appear to help (or hinder) bond performance
- Able to achieve bond to LDPE at much lower temperatures with OPE substrates vs. OPET substrates



Case Study #2: Adhesion Evaluation

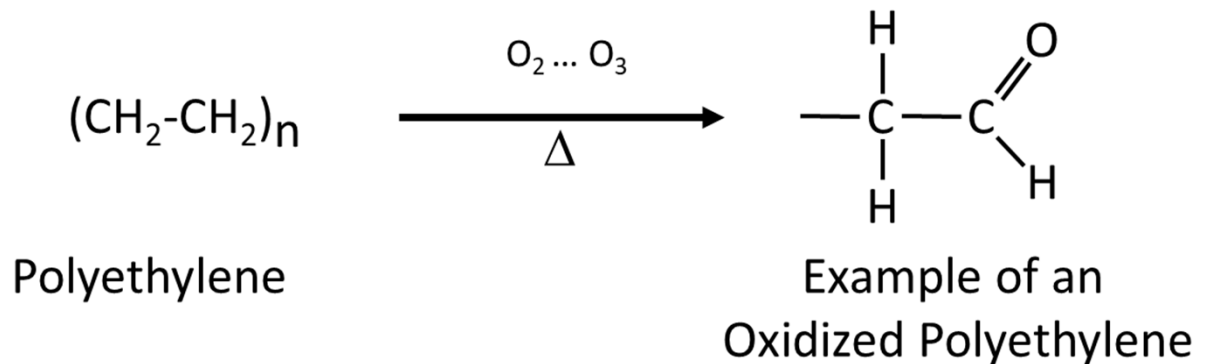
- Adhesion is **one of the most critical properties** in extrusion coating and laminating
- Adhesion = Package Integrity
- Adhesion requirements vary widely:
 - ❑ e.g., lower adhesion for easy open packaging
 - ❑ e.g., higher adhesion for cup stock and pouchmaking
- Polyethylene is the “glue” in extrusion coating and laminating. BOPP & BOPET films generally require a chemical bond. But, in an all-PE structure, what type of adhesion is occurring – Chemical or Mechanical?
- First, let’s look at each type of bond



Chemical Adhesion / Oxidation in Extrusion Coating

Chemical Bond - Oxidation

- Subjecting PE to elevated temperatures in the presence of oxygen (air – O₂) as well as ozone (O₃) will produce a reaction where PE molecules lose electrons to produce free radicals:



- Methods for improving chemical adhesion:
 - ☐ Higher melt temperatures
 - ☐ Increase time in air gap (TIAG) (*function of die height and line speed*)
 - ☐ Substrate treatment (*corona, flame, and primer*)



Mechanical Adhesion in Extrusion Coating

Mechanical Adhesion (*similar to a “heat seal”*)

- Driving Forces: *Temperature, Pressure, and Dwell*
- Methods for improving Mechanical Adhesion:
 - ☐ Increase nip force (*unless at max nip pressure*)
 - ☐ Increase melt temperature of PE
 - ☐ Increase chill roll temperature
 - ☐ Increase coat weight
 - ☐ Decrease Time in Air Gap (TIAG)
 - *Decreasing TIAG may have a minor effect on increasing mechanical adhesion, but could have a major impact on decreasing chemical adhesion*



Case Study #2: BOPE Adhesion Evaluation

Simple Two-factor Designed Experiment

- Die height (low = 6.5", high = 11.5")
 - ☐ Evaluate chemical and mechanical bond

- Line speed (low = 400 fpm, high = 800 fpm)
 - ☐ Pushing capabilities of polymer and equipment

- Ozone (ON, OFF)
 - ☐ Ozonation influence (*potential*)



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Standard Processing Conditions

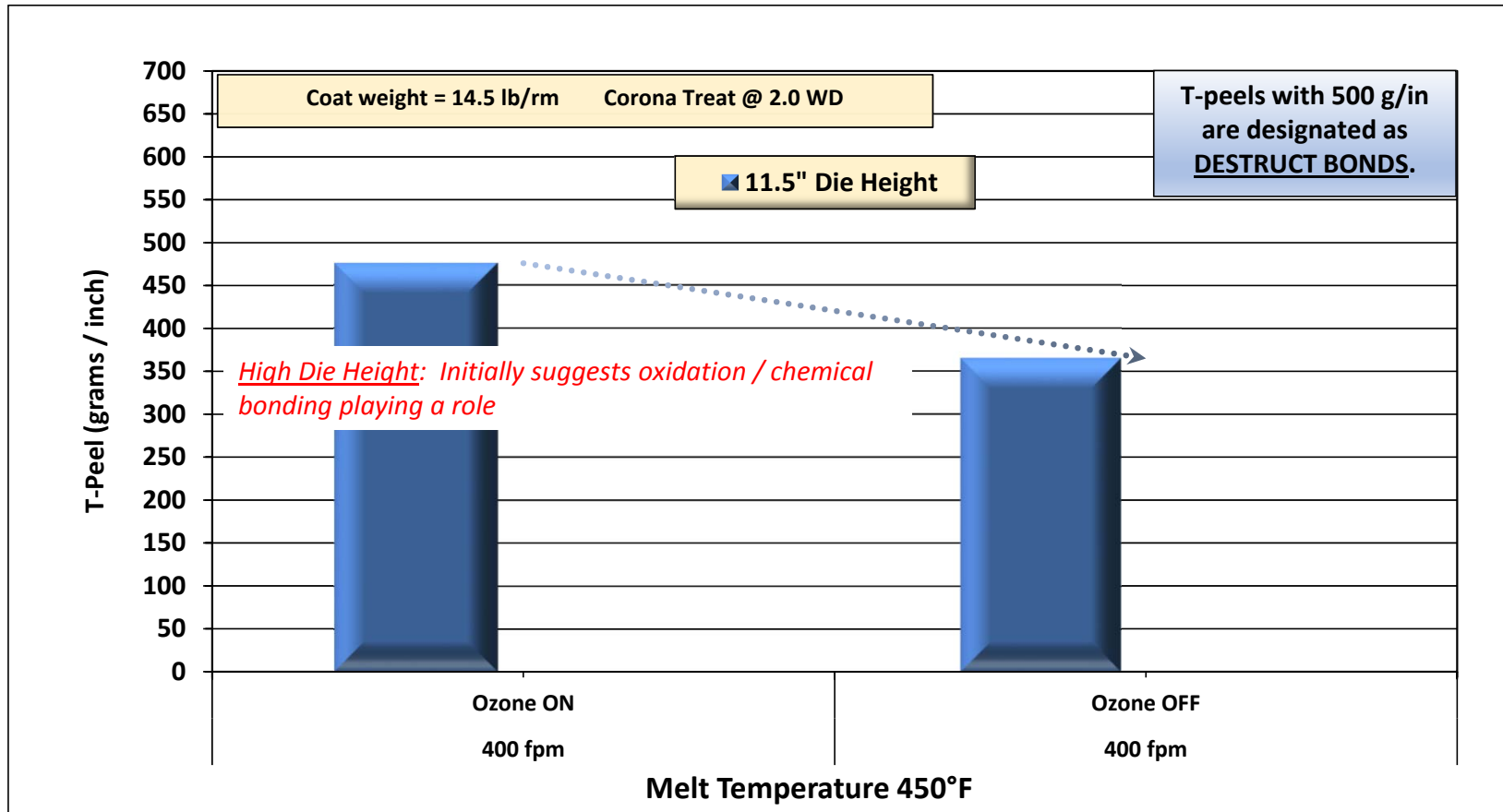
- Extrusion coat weight = 14.5 lb/rm
 - ❑ Standardized thermal mass

- Pre-treatment = Corona @ 2.0 WD
 - ❑ Prevent contaminants from interfering with study

- Melt temperature = 450 °F
 - ❑ Low temperature to detect adhesion mechanism below destruct bond potential – At higher temps, lock up was observed for either mechanism

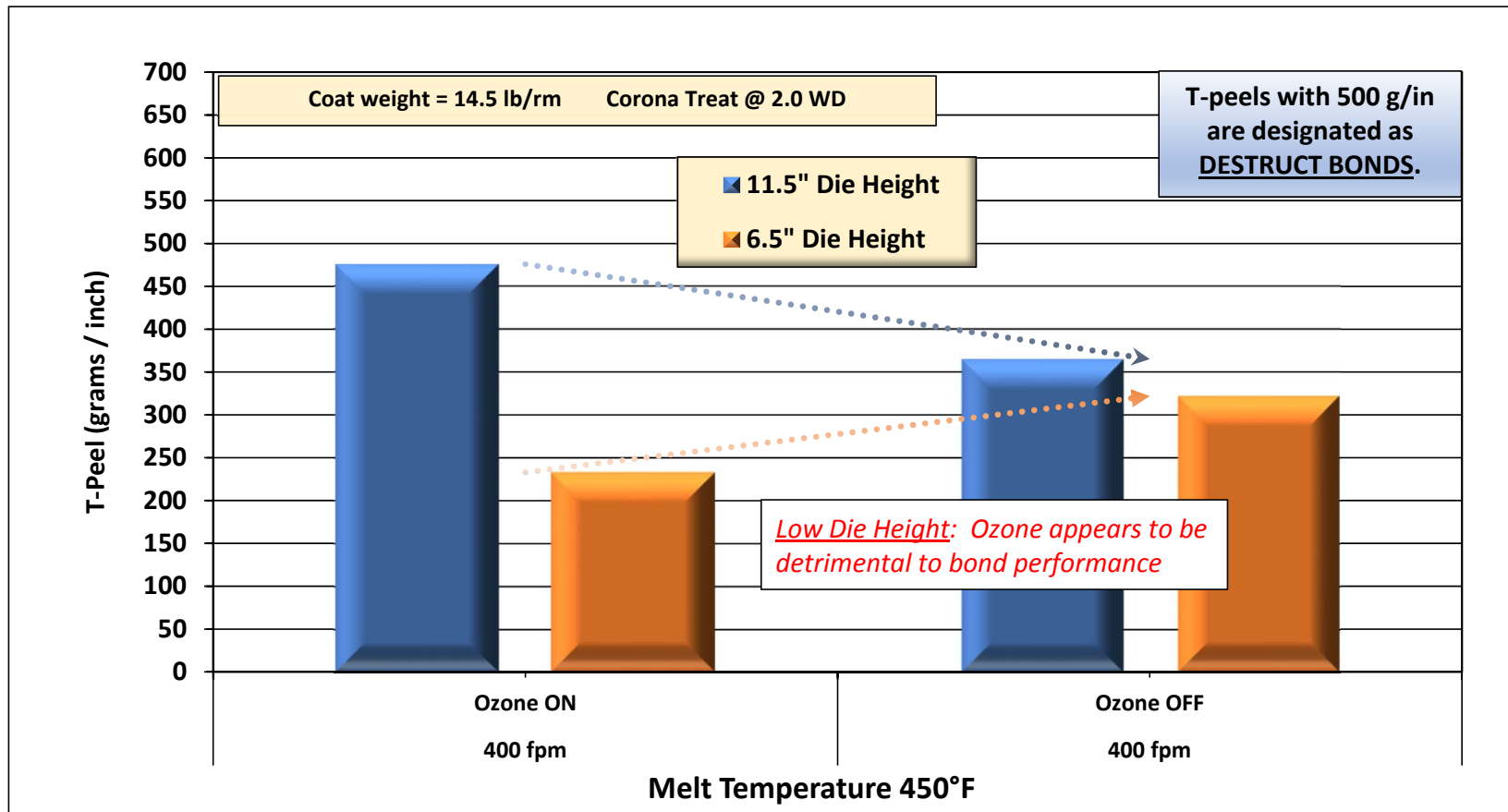


Case Study #2: BOPE Adhesion Evaluation @ 400 fpm



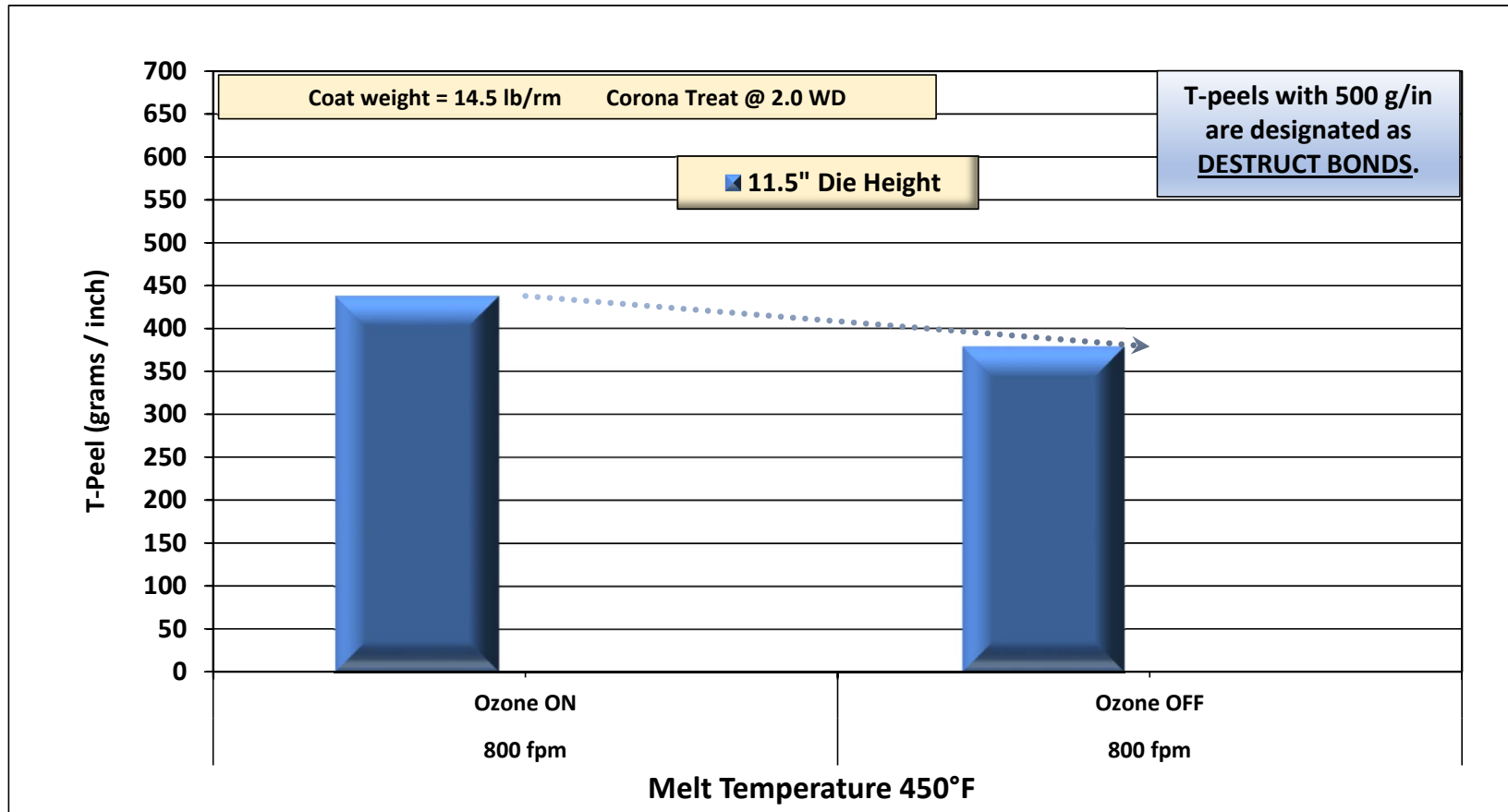


Case Study #2: BOPE Adhesion Evaluation @ 400 fpm



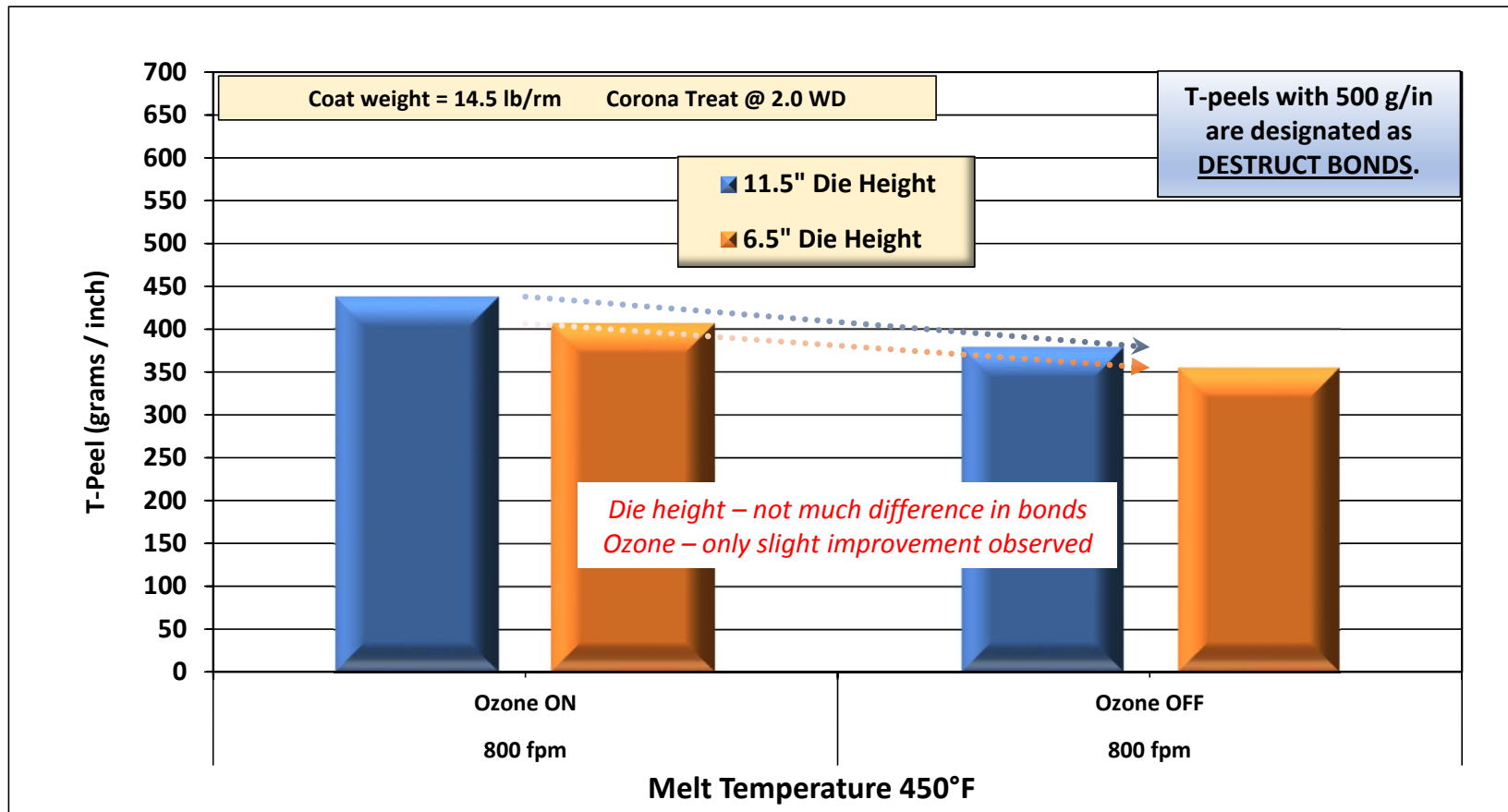


Case Study #2: BOPE Adhesion Evaluation @ 800 fpm



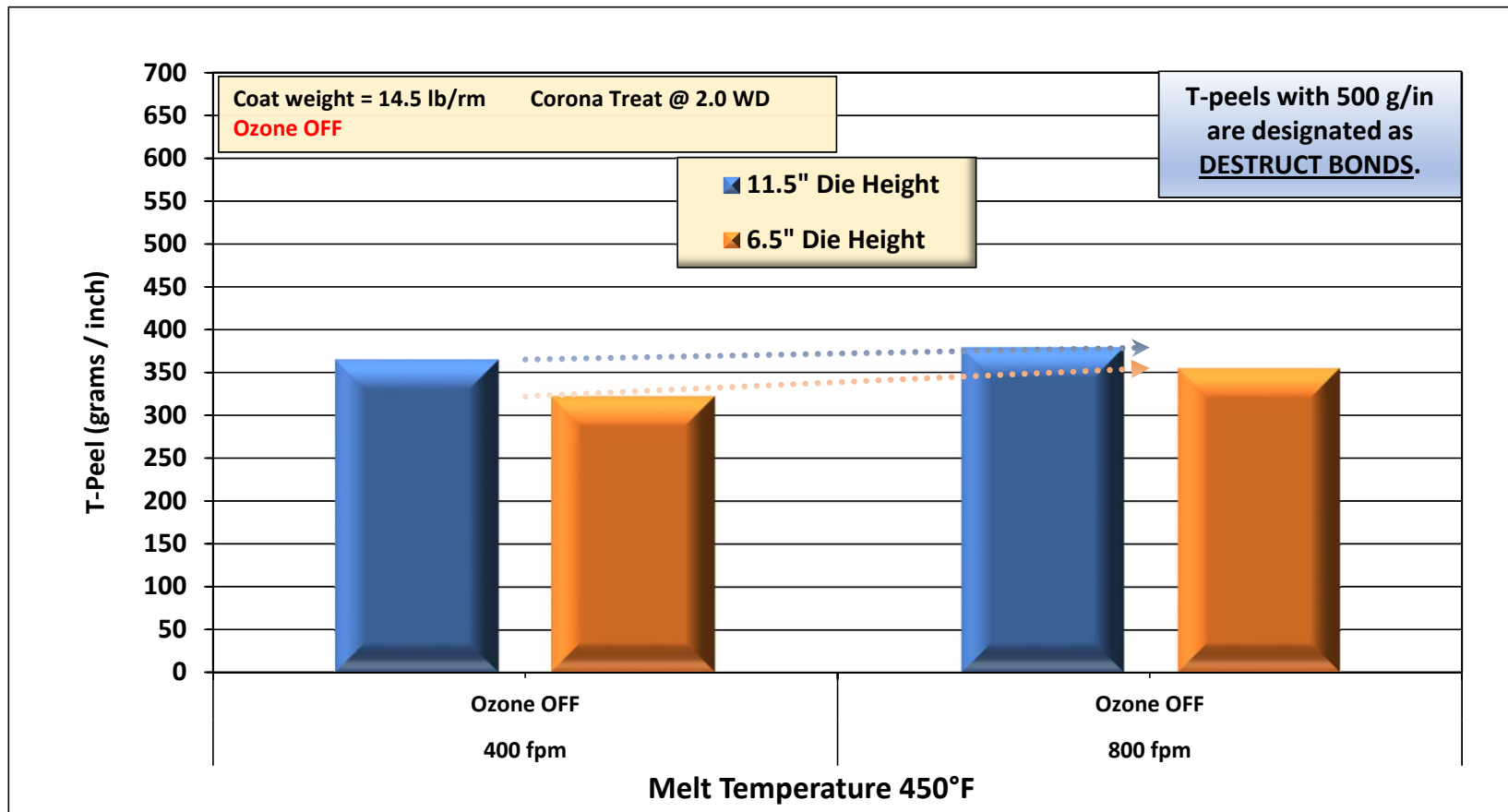


Case Study #2: BOPE Adhesion Evaluation @ 800 fpm





Case Study #2: BOPE Adhesion, Ozone OFF vs. Line Speed





Case Study #2: OPE Adhesion Observations Summary

- Low Line Speeds @ 400 fpm / Low Melt Temperature (450 °F)
 - ❑ High die height, big impact on bonds – suggests oxidation & chemical bond @ set conditions
 - ❑ Low die height, lower bond performance
 - Suggests mechanical adhesion took over / big drop in chemical adhesion
 - Ozone made bonds worse – could it be a “cooling effect”? (*Ozone is blown onto the melt curtain at nip*)
- Higher Line Speeds @ 800 fpm / Low Temperature (450 °F)
 - ❑ Die height did not impact bond performance – less oxidation coming into play
 - ❑ A shorter TIAG - more mechanical adhesion influence (higher line speed @ lower gap)?
- Ø Appears to be an opportunity to process LDPE at much lower temperatures / higher line speeds, as well as lower possible air gap settings, when processing with OPE substrates

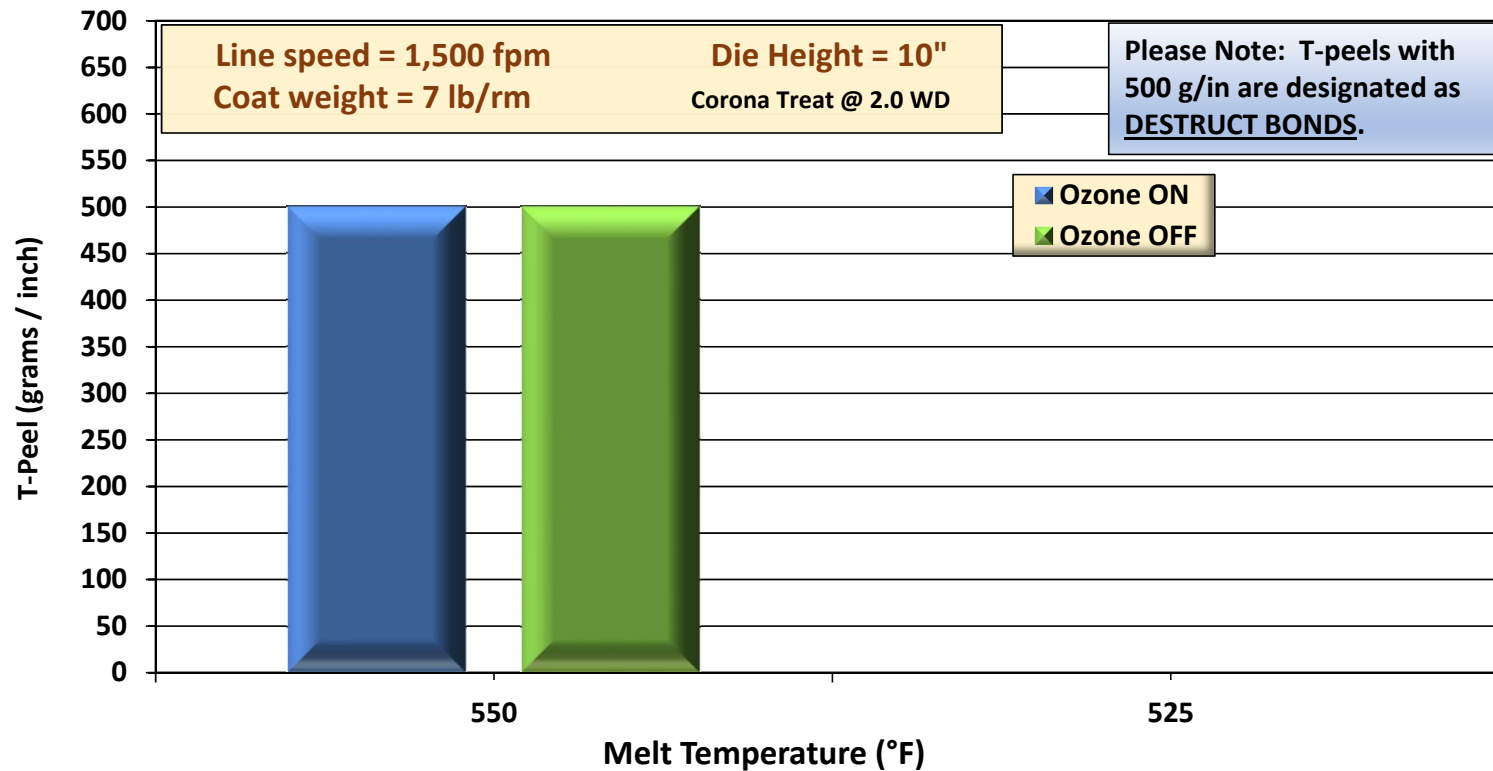


Case Study #3: BOPE @ Converter Processing Profiles

- **Goal:** Process BOPE film at typical converter settings
 - ☐ Run line speed @ 1,500 fpm
 - Relevant converter line speed
 - ☐ Extrusion Coat Weight @ 7 lb/rm
 - Relevant coat weight, but also lower thermal mass
 - ☐ Die Height @ 10"
 - Standardized die height
 - ☐ Corona Pre-treatment = 2.0 WD
 - ☐ Ozone = ON / OFF
 - Observe any improvements
- ☐ Increased Melt Temperature (550 °F)
 - Issues with drawing the polymer melt down and back pressure while reaching higher linespeeds @ 450 °F

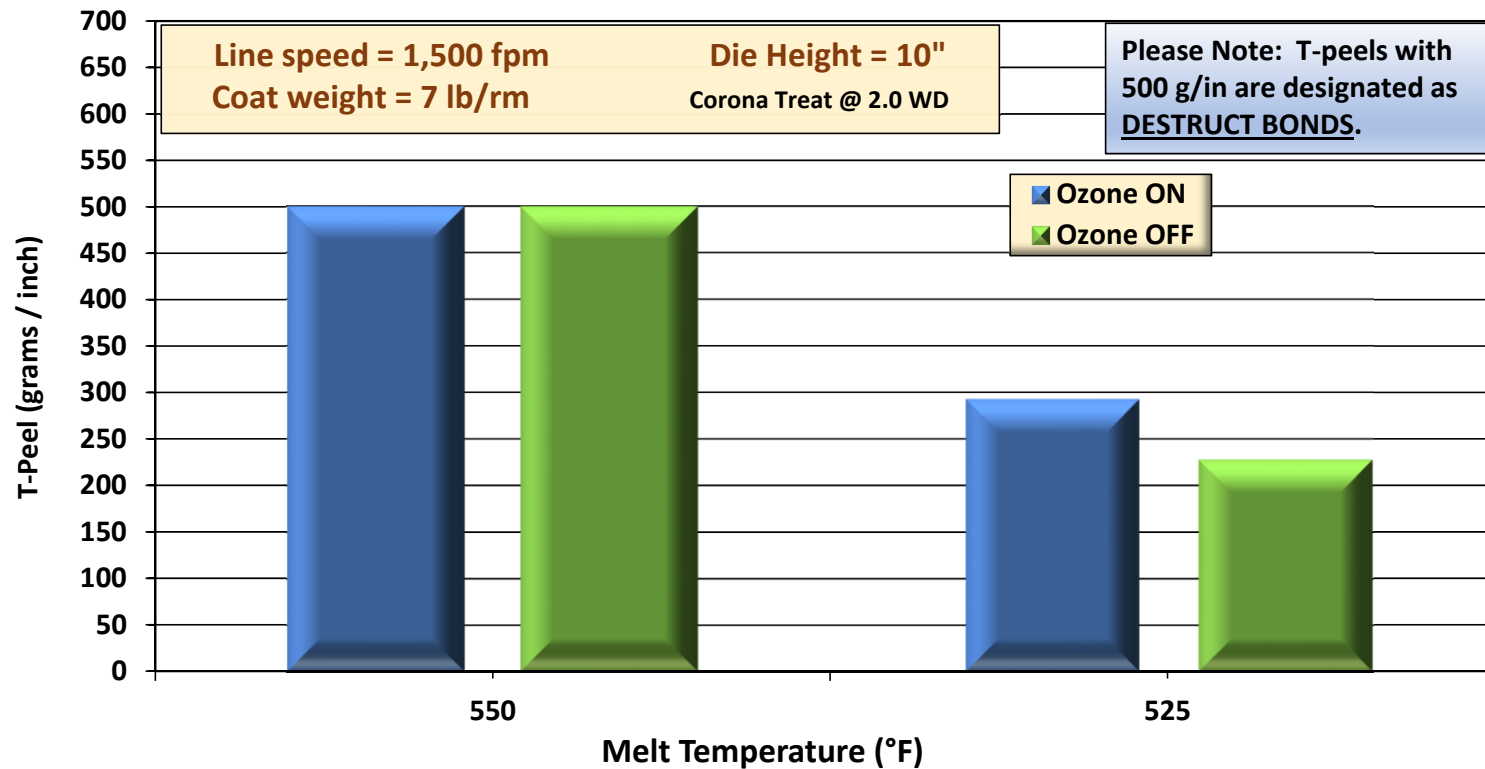


BOPE Coating / Lamination – Converter Processing





BOPE Coating / Lamination – Converter Processing





Summary & Conclusions – Converter Simulation

- Able to achieve destruct bonds with BOPE and MD-OPE @ 550 °F (*much lower than with typical conditions for BOPP & BOPET substrates*)
- Melt temperature had greatest effect on bond performance
- Ozone had slight influence at lower temperature (525 °F) on bond performance
- Converters may be able to take advantage of much lower process temperatures when processing OPE substrates



Process Challenges / Observations with OPE Film:

- Observed an 1/8" reduction in substrate width at tension ranges ~ 0.75 – 1.0 PLI
- OPE substrates started to show signs of TD shrinkage (~1.5%) in the primer dryer oven @ ~190 °F, 400 fpm. However, primer application was not needed for the OPE substrates (not printed)



Process Challenges / Observations with OPE Film:

- No burn-through was experienced during startups

CONDITIONS – EXTRUSION EQUIPMENT

- ☐ Melt temperature = 600 °F
 - Extruder profile temps (350, 450, 550, 600 °F, etc.)
 - Die & feedblock temps = 600 °F
- ☐ Chill drum = 70 °F
- ☐ Extrusion nip roller, not cooled
 - Extrusion back up nip roller = 45 °F
- ☐ Extruder in DROOL SPEED while down
- ☐ Unwind Tension – Low (~0.75 PLI)



Process Challenges / Observations with OPE Film:

- No burn-through was experienced during startups

CONDITIONS – EXTRUSION EQUIPMENT	STARTUP METHOD
☐ Melt temperature = 600 °F - Extruder profile temps (350, 450, 550, 600 °F, etc.) - Die & feedblock temps = 600 °F ☐ Chill drum = 70 °F ☐ Extrusion nip roller, not cooled - Extrusion back up nip roller = 45 °F ☐ Extruder in DROOL SPEED while down ☐ Unwind Tension – Low (~0.75 PLI)	☐ Line speed set to 150 fpm (ramp up) ☐ Line speed = 150 fpm, - Extruder carriage brought in to extrusion nip ☐ Poly @ DROOL SPEED hits the extrusion nip - Line speed is set to FULL SPEED (ramp up) - Extruder RPM's set to FULL SPEED (ramp up)



SUMMARY & CONCLUSIONS

- BOPE & MD-OPE substrates achieved bonds at lower temperatures ($\Delta T > 100$ °F) as compared with the BOPET substrate
- Depending on conditions, a higher melt temperature could achieve destruct bonds, regardless of die height or ozonation, suggesting a more mechanical / sealing mechanism. At lower temperatures / conditions, chemical adhesion become more influential
- Converter Rates Simulation: Achieved destruct bonds @ 1,500 fpm, 7 lb/rm with a melt temperature @ 550 °F
- Running @ such a low melt temperature (450 °F), pushing extrusion equipment & drawdown capabilities of the LDPE extrusion coating resin (16 MI / 0.917 density)
- Slight TD shrinkage observed when using dryer oven; however, primer was not necessary
- While performing the case study, no burn-through of the OPE substrates was experienced
- If interested, future trial work can be considered



Conclusion

BOPE films processed in this study did not appear to present significant processing challenges and may provide an opportunity for converters to lower their processing temperatures, while working towards producing a mono material structure for recycling



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➤ CPChem EC Line Technicians:

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➤ CPChem Management:

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Supplying BOPE films



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THANK YOU!

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