# Major Markets & Applications for Beta Nucleated Polypropylene

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# Outline

1. Attributes of beta crystallinity and differences from alpha crystallinity
2. Major Markets
    1. Geogrids
    2. Welding & Heat Sealing
    3. Thermoforming
    4. Pressure Pipe
    5. Oriented film
    6. Impact Improvement
3. Summary and Conclusions

# Differences Between Alpha and Beta Crystal Phases in PP

## Alpha Phase

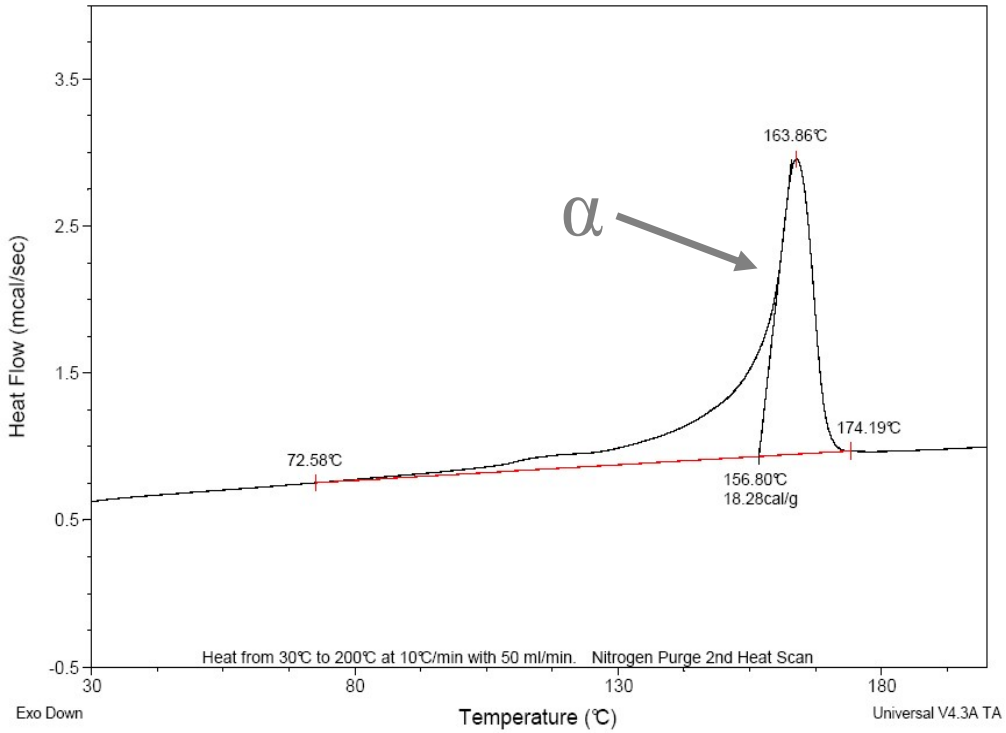
- Melts at ~ 164 $^{o}$C
- Most common phase
- Many nucleants known: Some nucleants are also clarifiers
- Alpha nucleants increase modulus and reduce cycle time

## Beta Phase

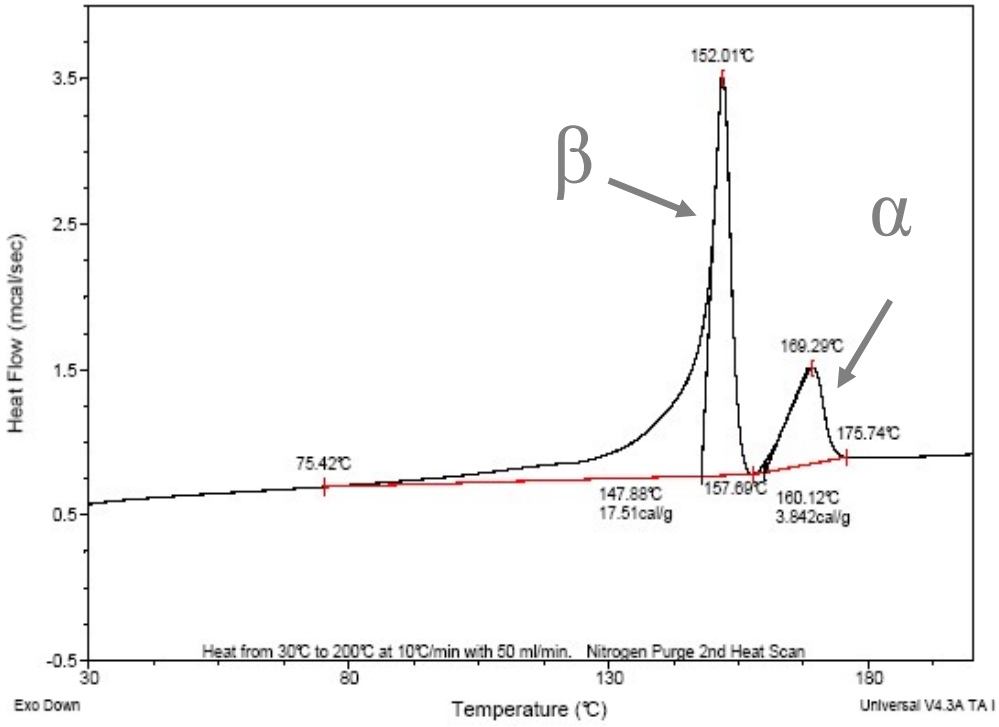
- Melts at ~ 150 $^{o}$C
- More ductile: Increases impact strength and break elongation with small losses in tensile strength and flexural modulus
- Very few beta nucleants are known
- Microvoids if stretched in solid state
- Generally cannot be produced in alpha nucleated PP

# DSC Melting Curves for Alpha and Beta PP
## (2nd Heat Scans)

### Alpha PP

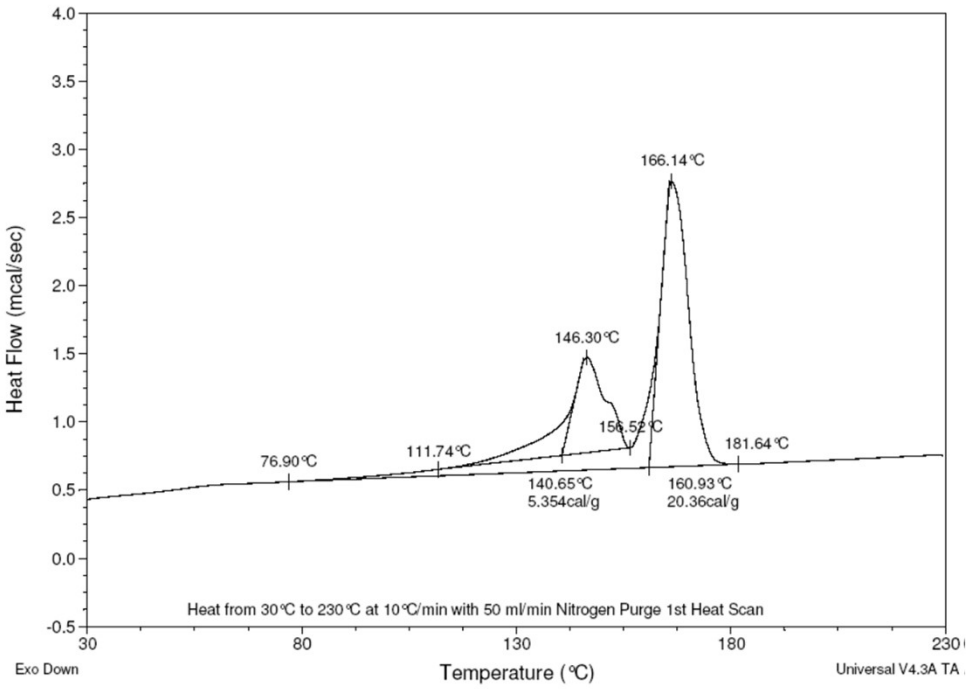



### Beta PP

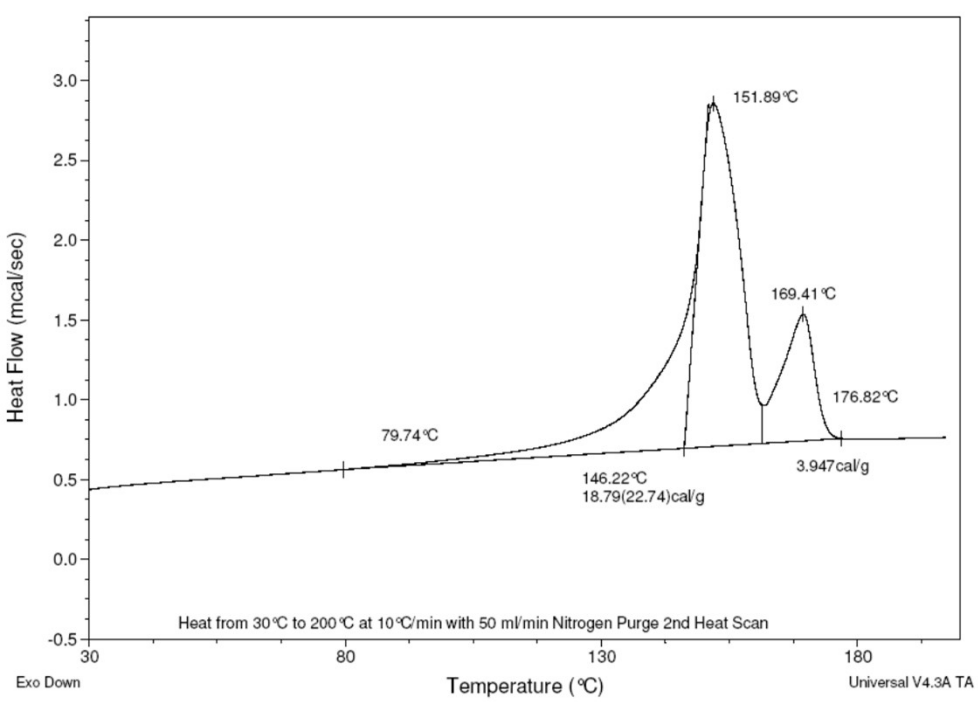


# DSC Data on Beta Nucleated Film Extruded at Recent Slit-Film Fiber Trail – 1.0% MPM 1113

**1st Heat Scan**

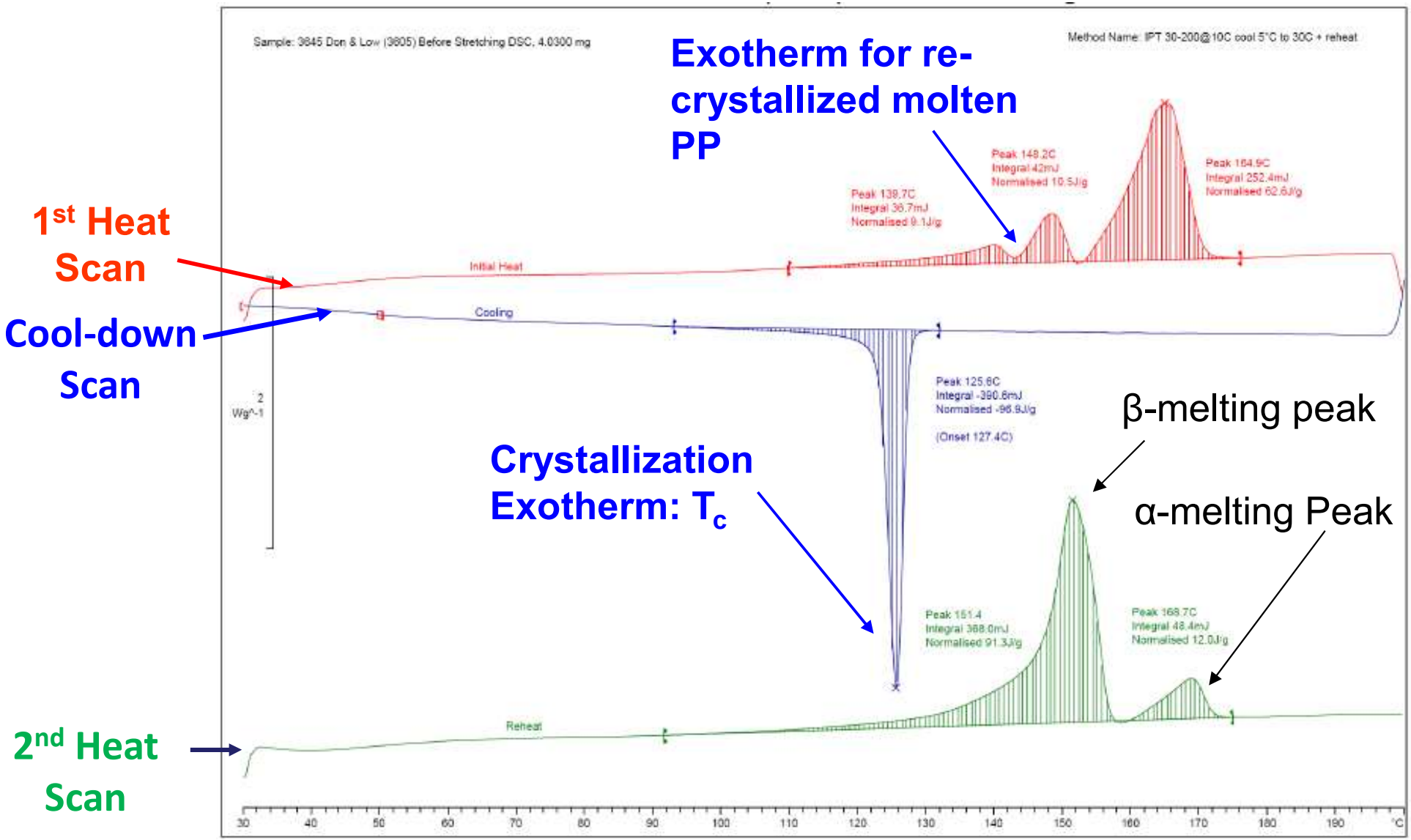



**2nd Heat Scan**

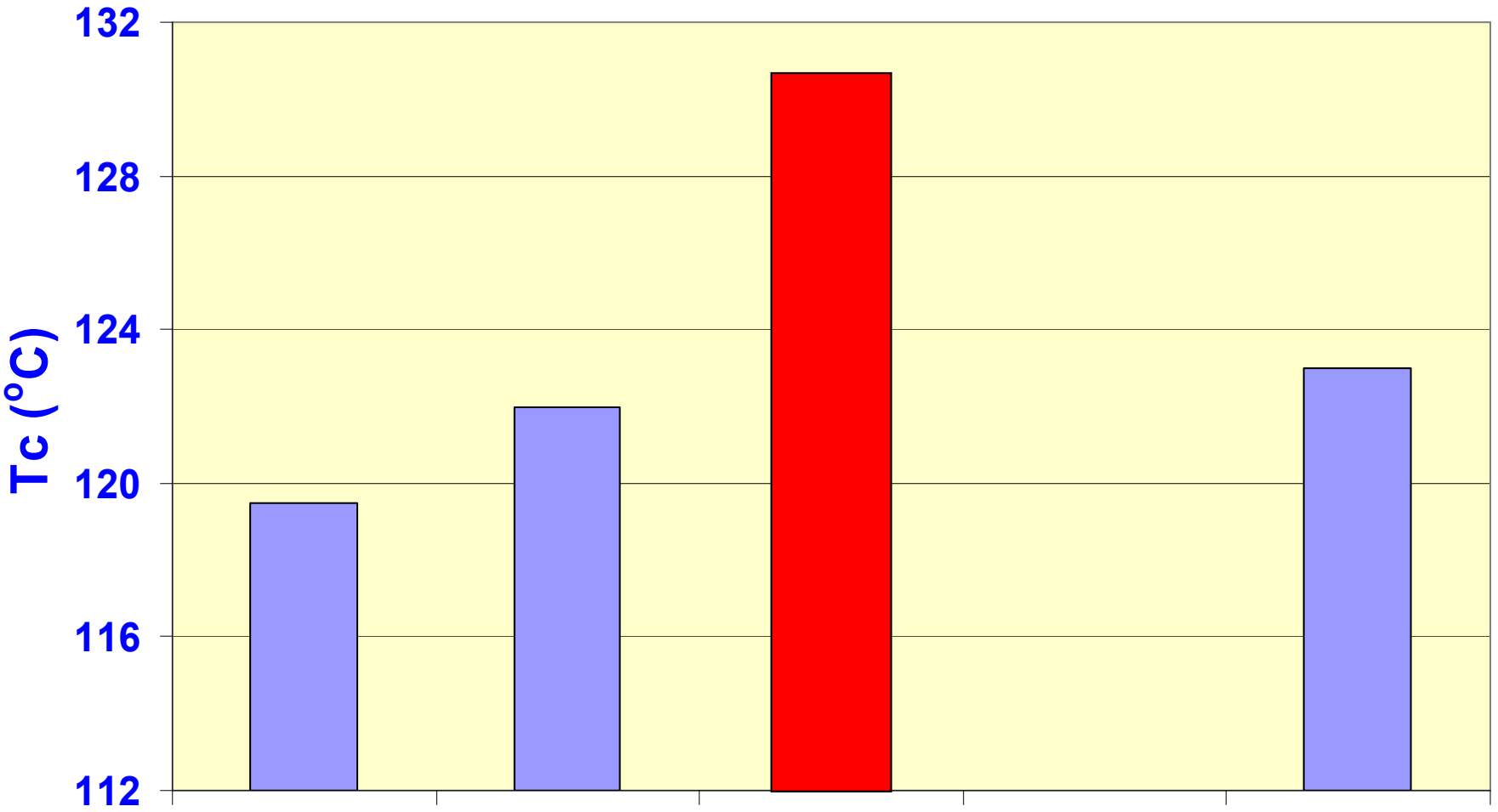



Tc = 122.3 °C

# DSC Scans of Extruded PP Sheet Samples



# Crystallization Temperatures for Nucleated Polypropylene




rmation

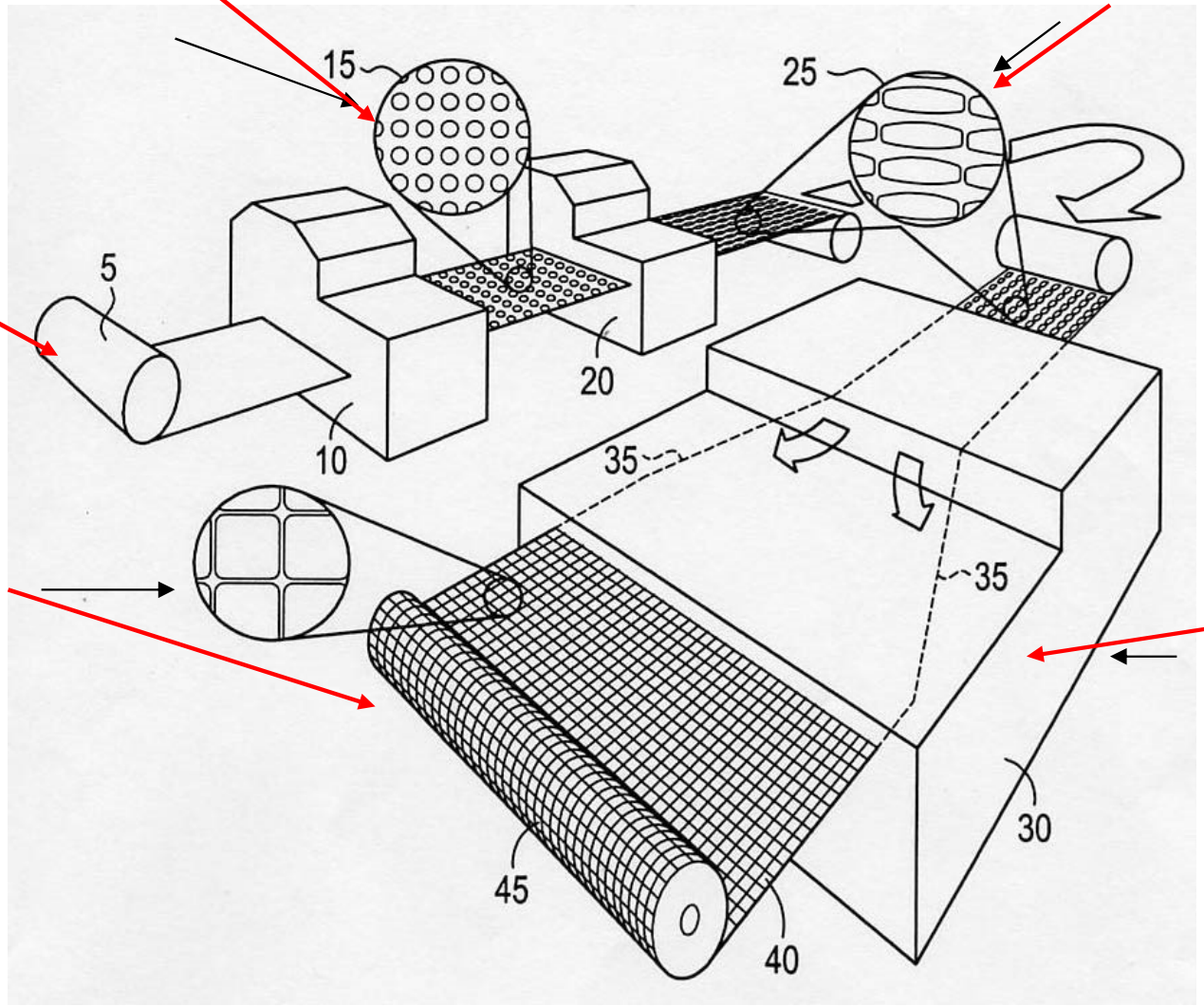
# Major Markets

# Geogrids

# Geogrid Production Process

Holes Punched in Sheet

Perforated Sheet after MD Orientation



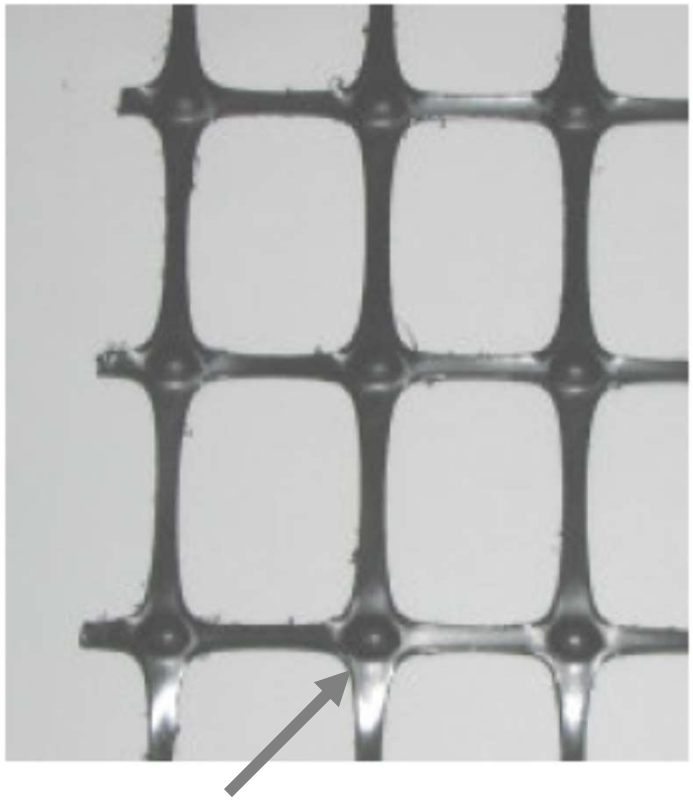

Extruded PP Sheet

Biaxially stretched Geogrid

Transverse Stretching of Sheet

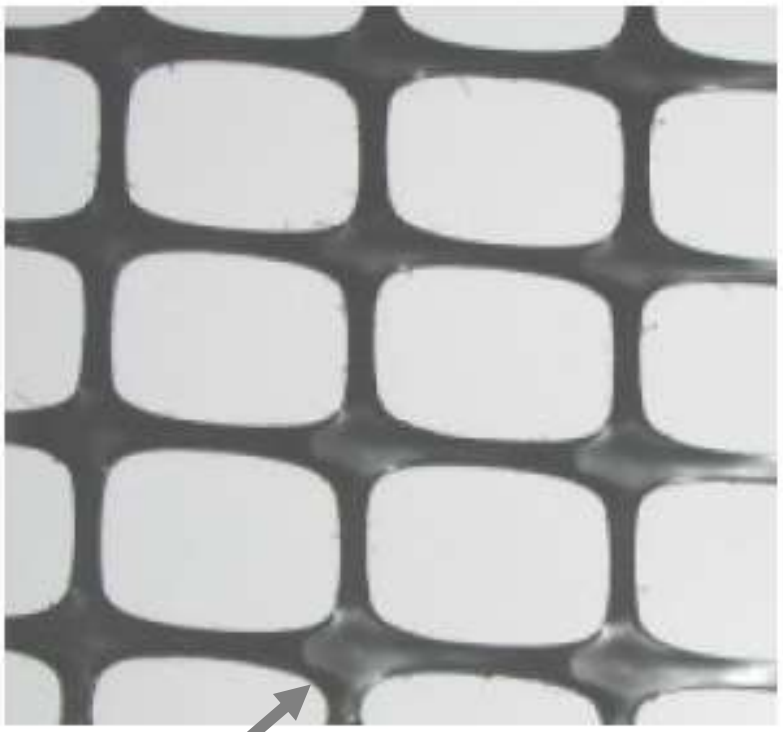
# Geogrid Made With and Without The Beta Nucleation

## Non-nucleated



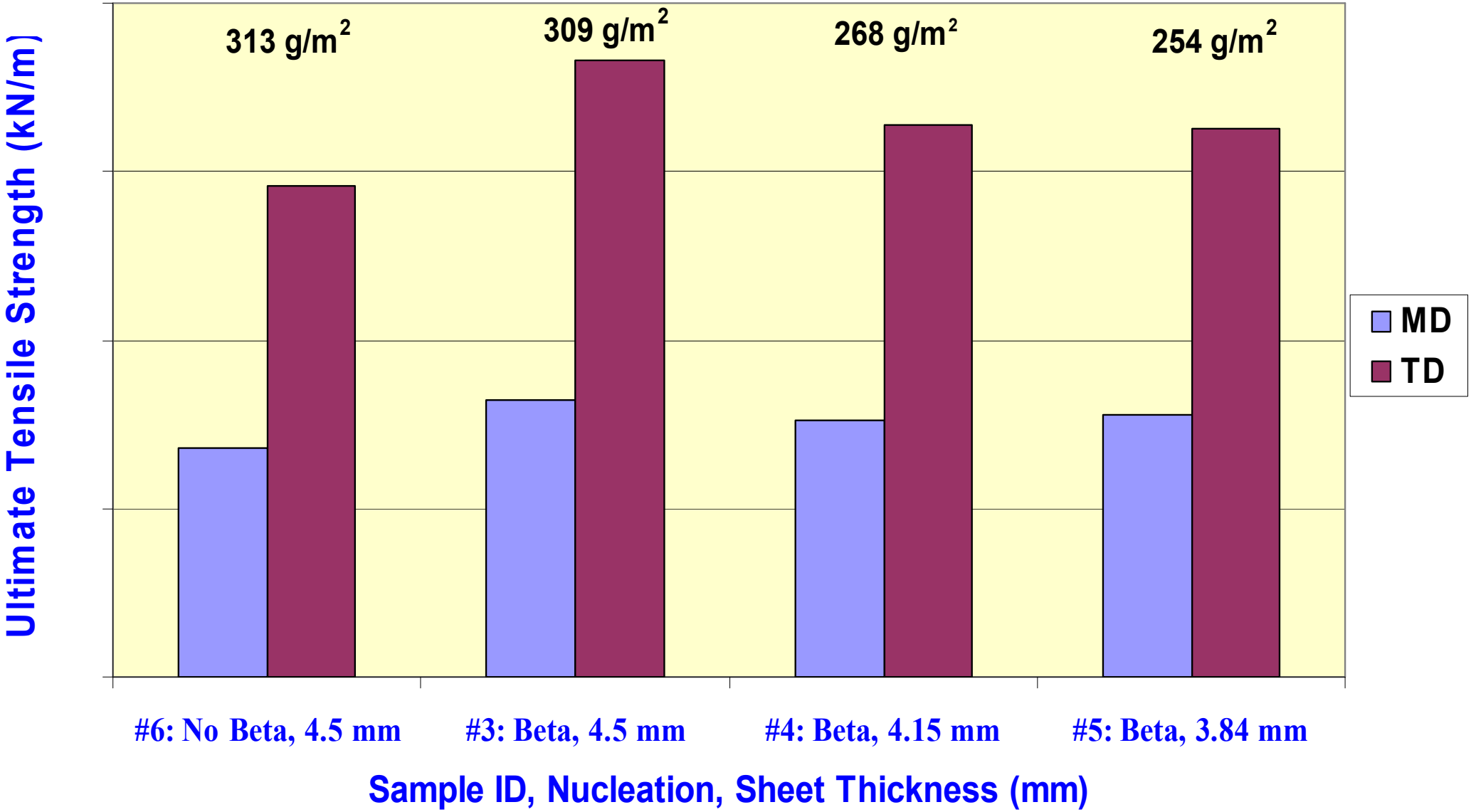
Node thickness of 3.4 mm

## Beta Nucleated



Node thickness of 2.3 mm

# Ultimate Tensile Strength of PP Geogrids With and Without Beta Nucleation



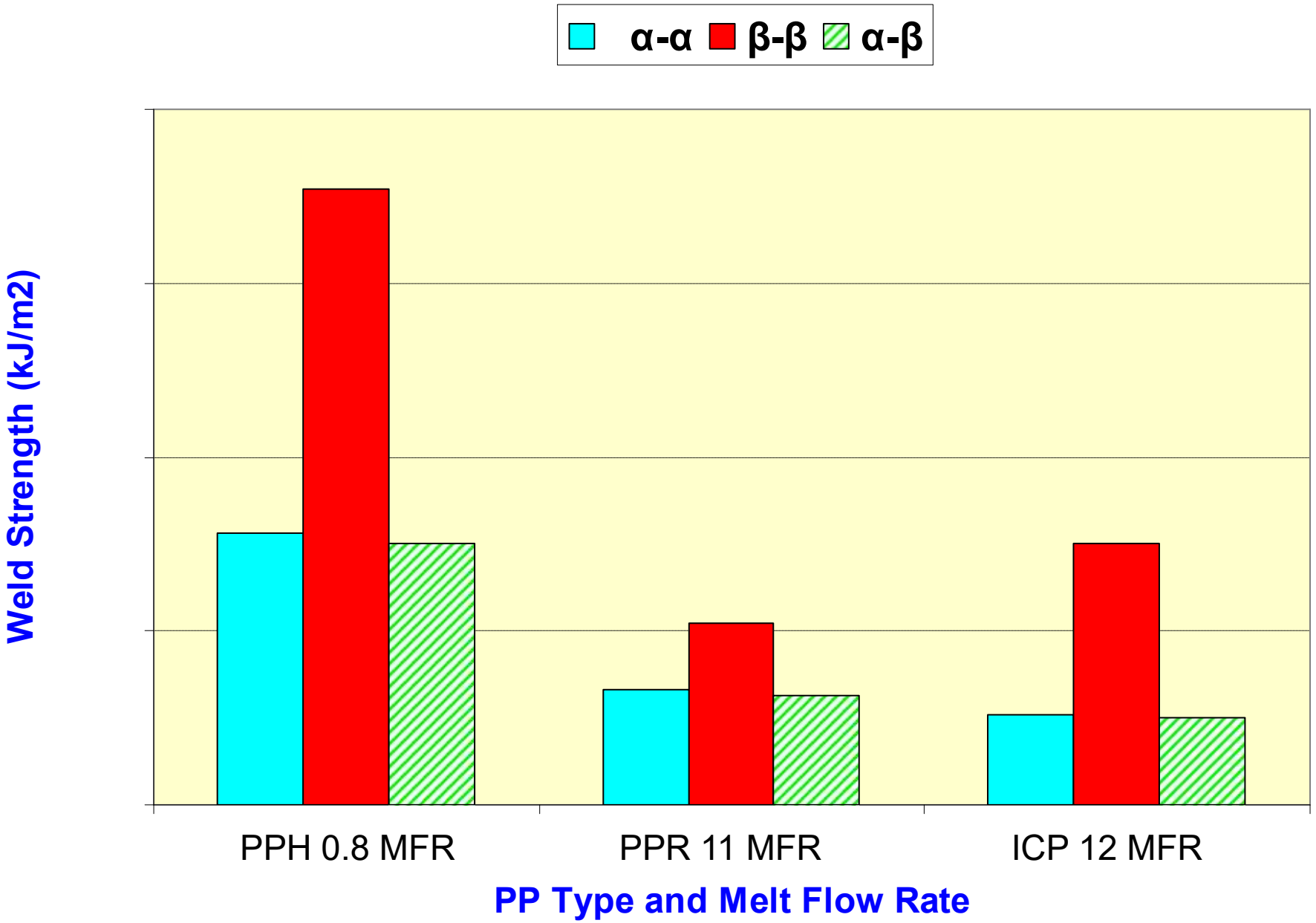
# Advantages of Beta Nucleation in the Production of Geogrids

- Higher tensile strength allowing for up to 20% down-weighting
- Can be run at higher production speeds

# Welding & Heat Sealing

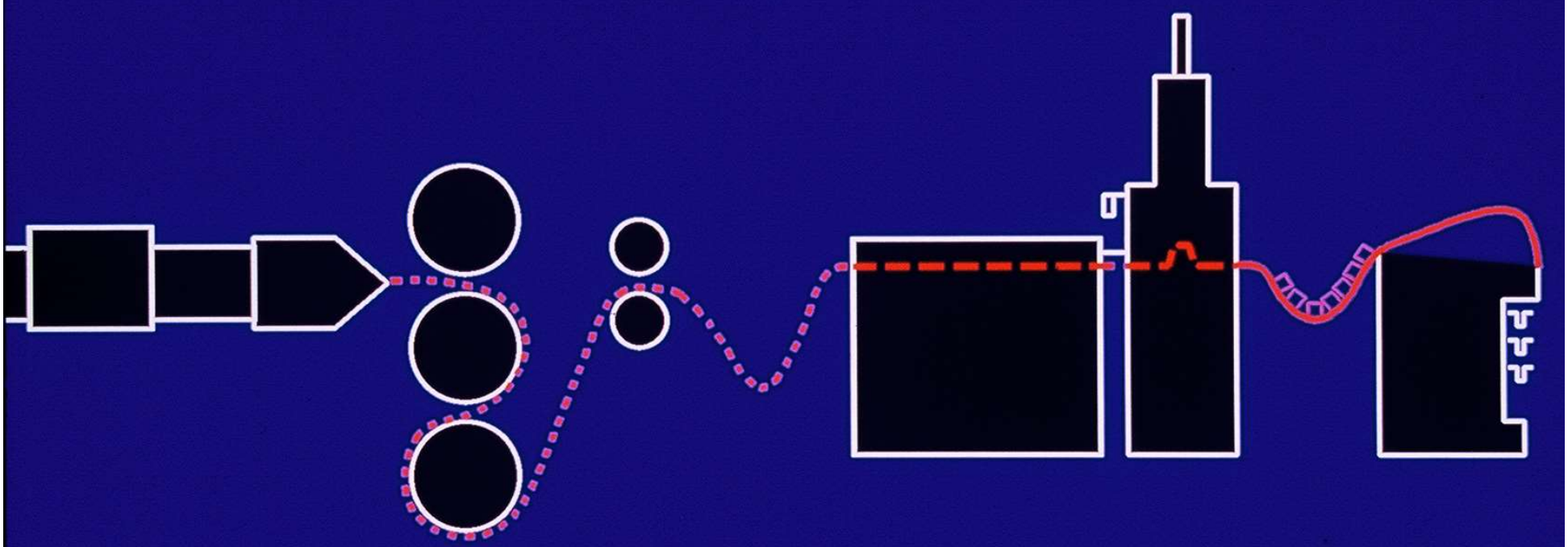
- Beta nucleation leads to much higher weld strengths in polypropylene

# Vibration Weld Strength of Beta vs Alpha Crystalline Polypropylene



# Thermoforming

# Schematic of In-Line Thermoforming



Extrusion Heating Forming Trimming

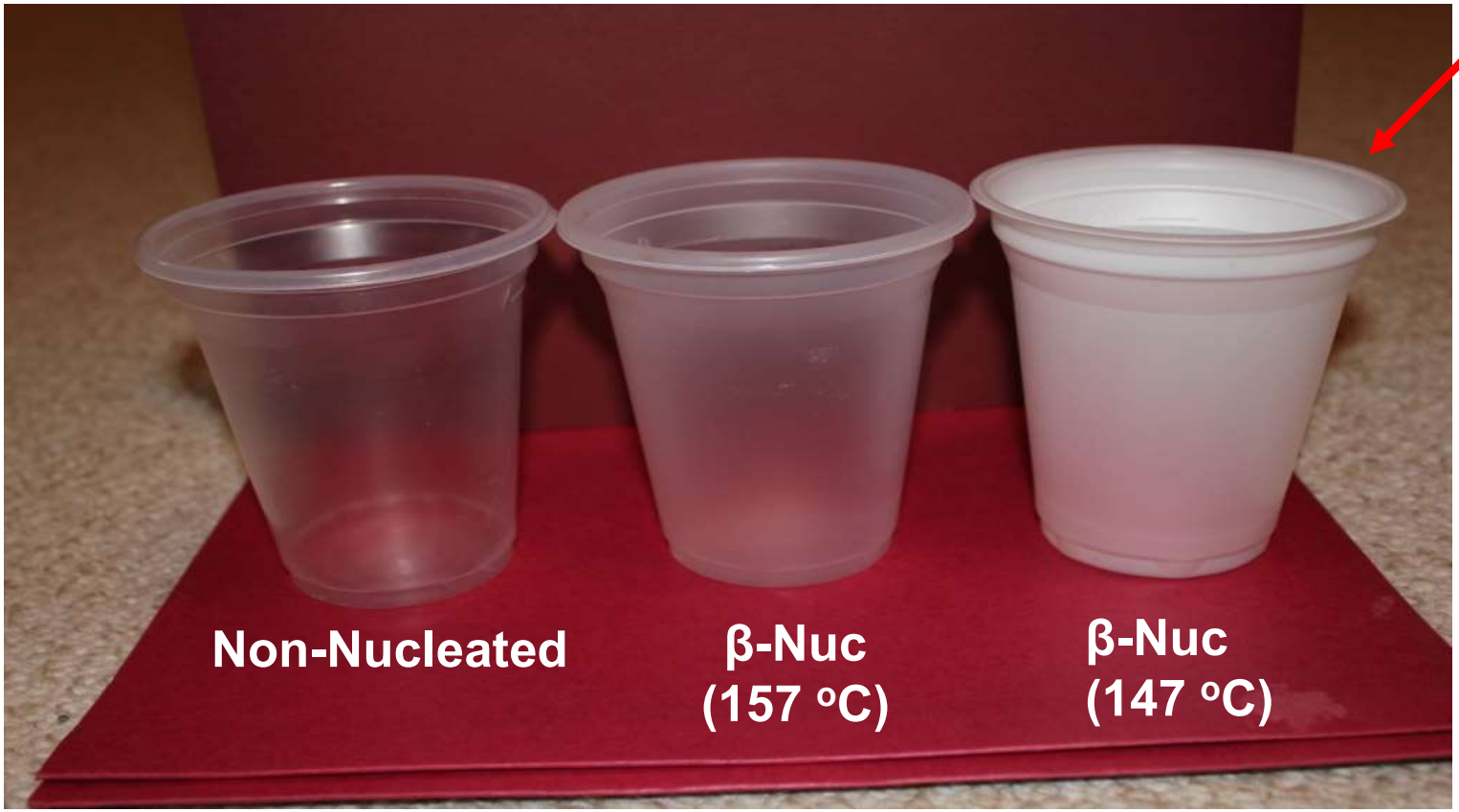
# Thermoformed 16 oz Cups Made with Non-nucleated and β-Nucleated PP

**Note: No $TiO_2$ used in Beta nucleated HPP**


**Non-nucleated** **Beta Nucleated**

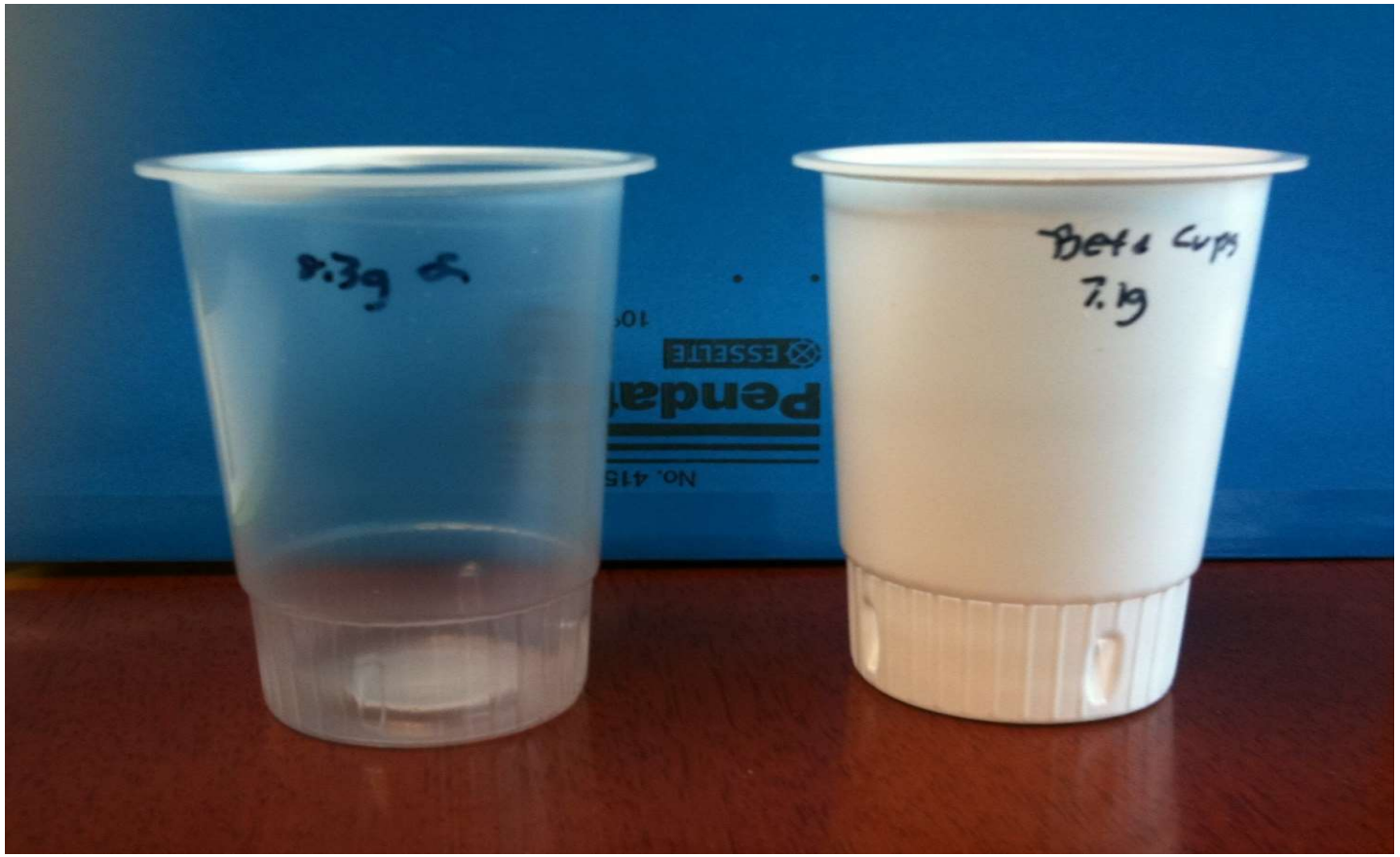
# Cups Thermoformed at Different Temperatures

Note the whiteness produced when the forming occurs below the Tm of the Beta phase



# Solid Phase Formed Cups Made with & without β-nucleation

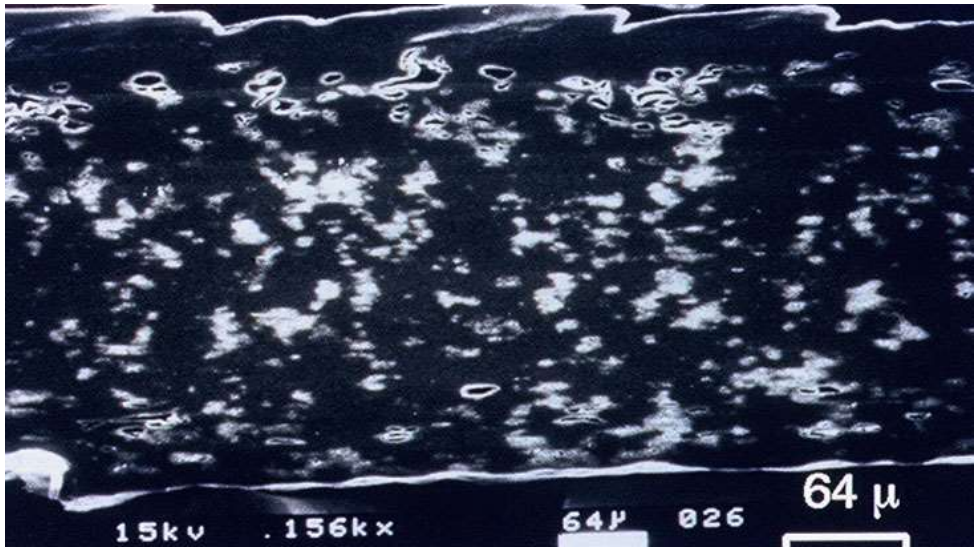
**Note: No $TiO_2$ used in Beta nucleated HPP**



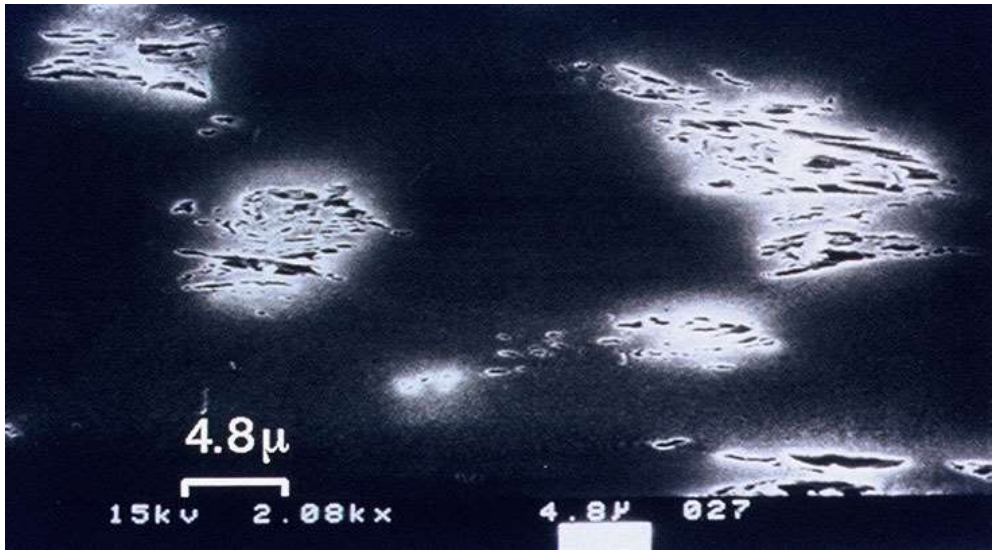

**Non-nucleated Cup: 8.3g** **β-nucleated Cup: 7.1g**

# SEM Micrographs of Microvoided Container Cross-section

**Note: Isolated clusters of sub-micron sized voids in the container sidewall produce whitening and density reduction without loss of barrier properties**



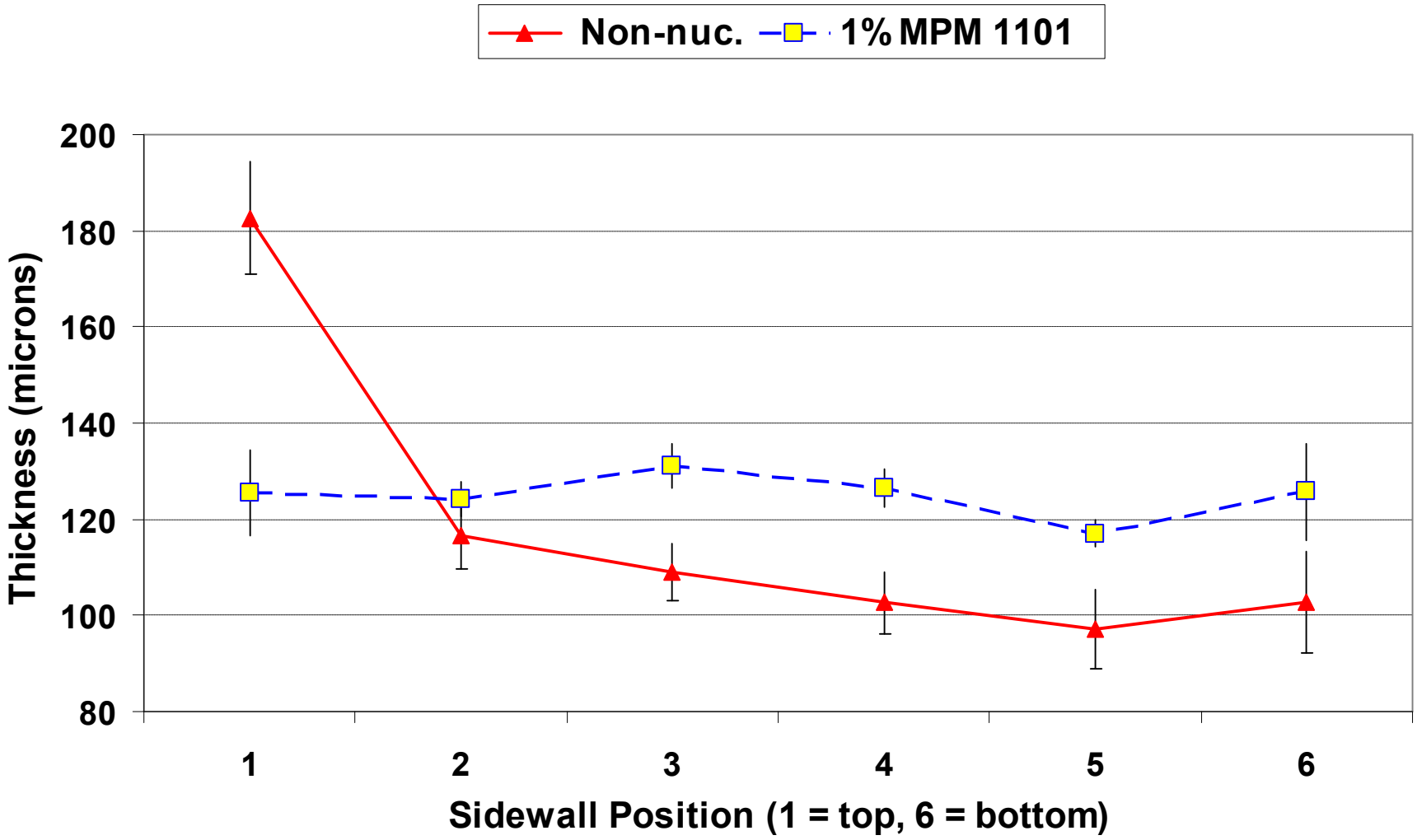

Low Magnification




High Magnification

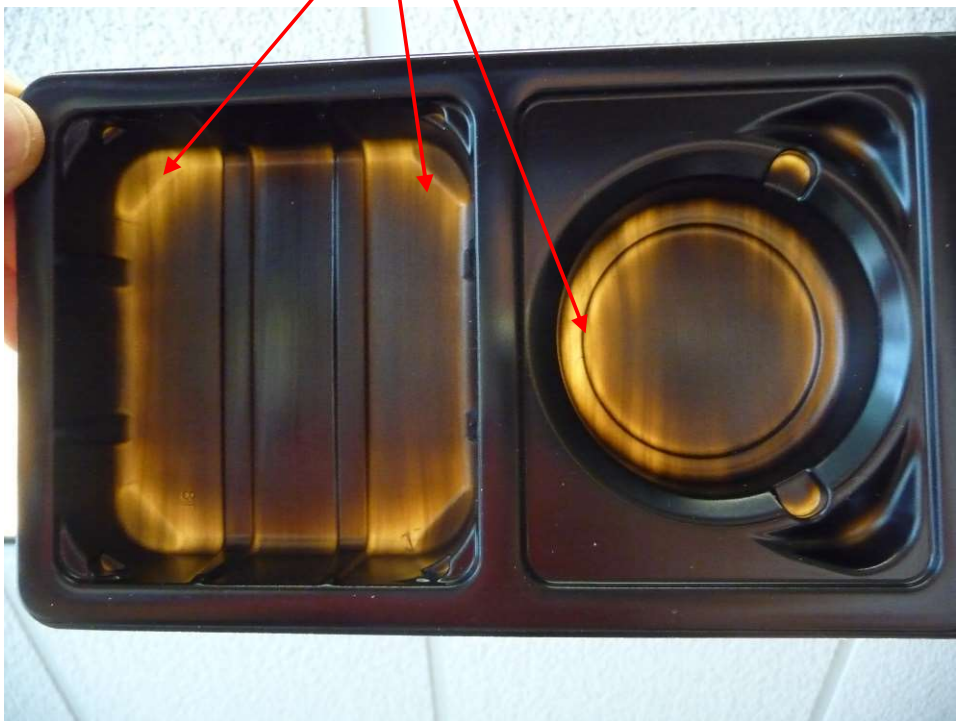
**Note: The microvoids are close celled and do not lead to breathability**

# Sidewall Thickness Distribution in Melt-Phase Formed Cups



# Backlit Trays

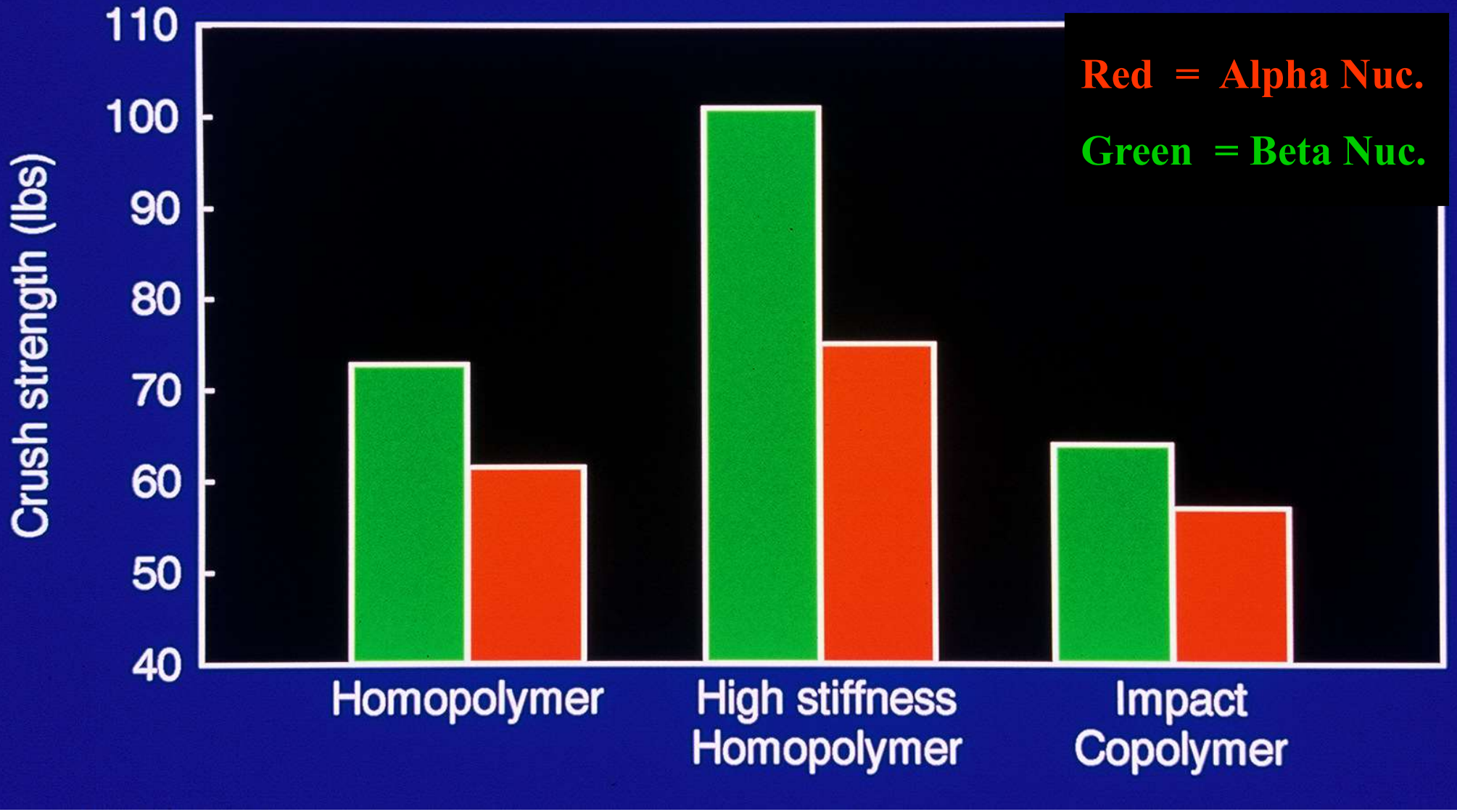
Note thin spots



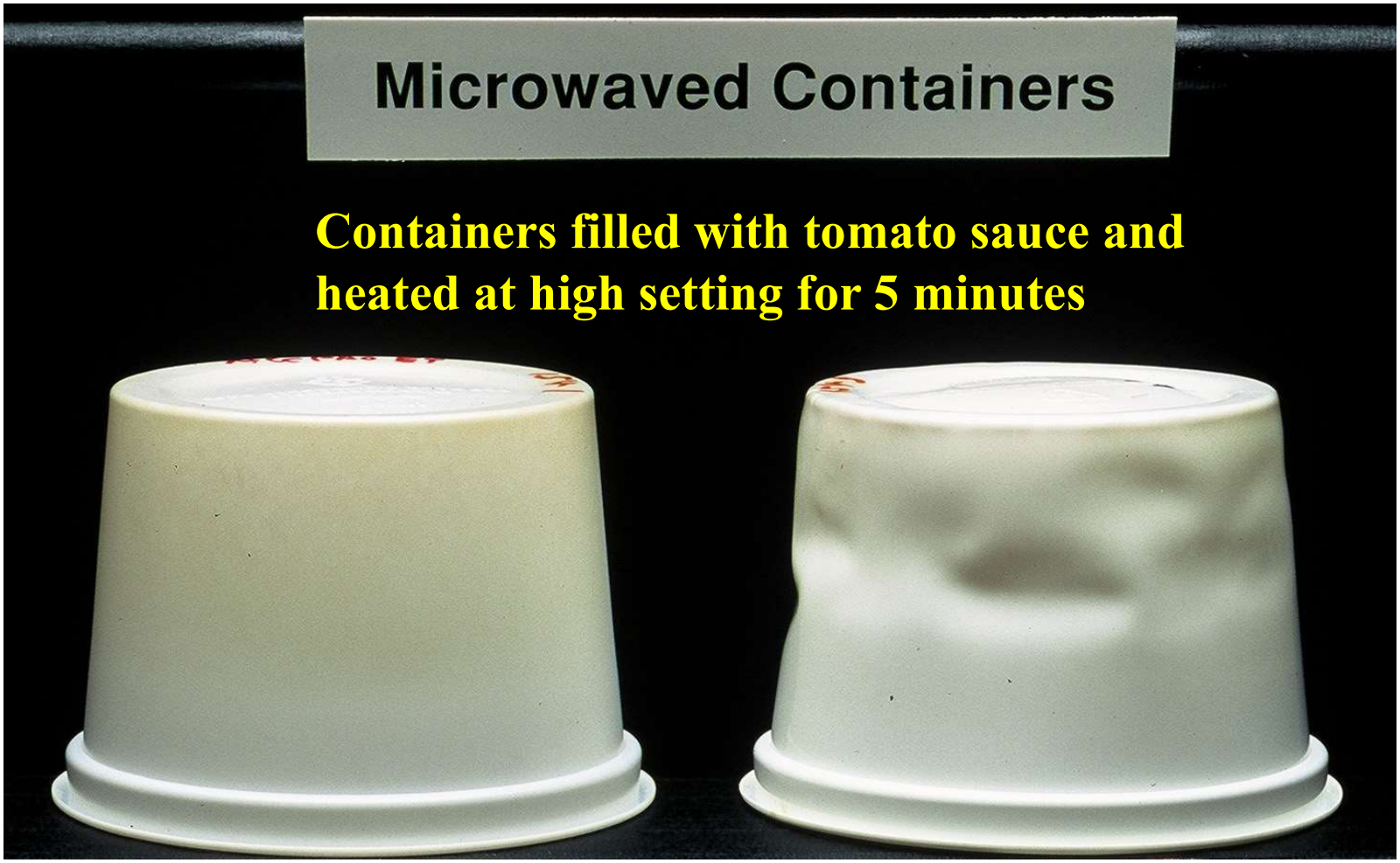
**Control Tray – No Beta**

**Tray with 1% MPM 2000**

# Top Load Crush Strength of Polypropylene Containers With and Without β-Nucleation

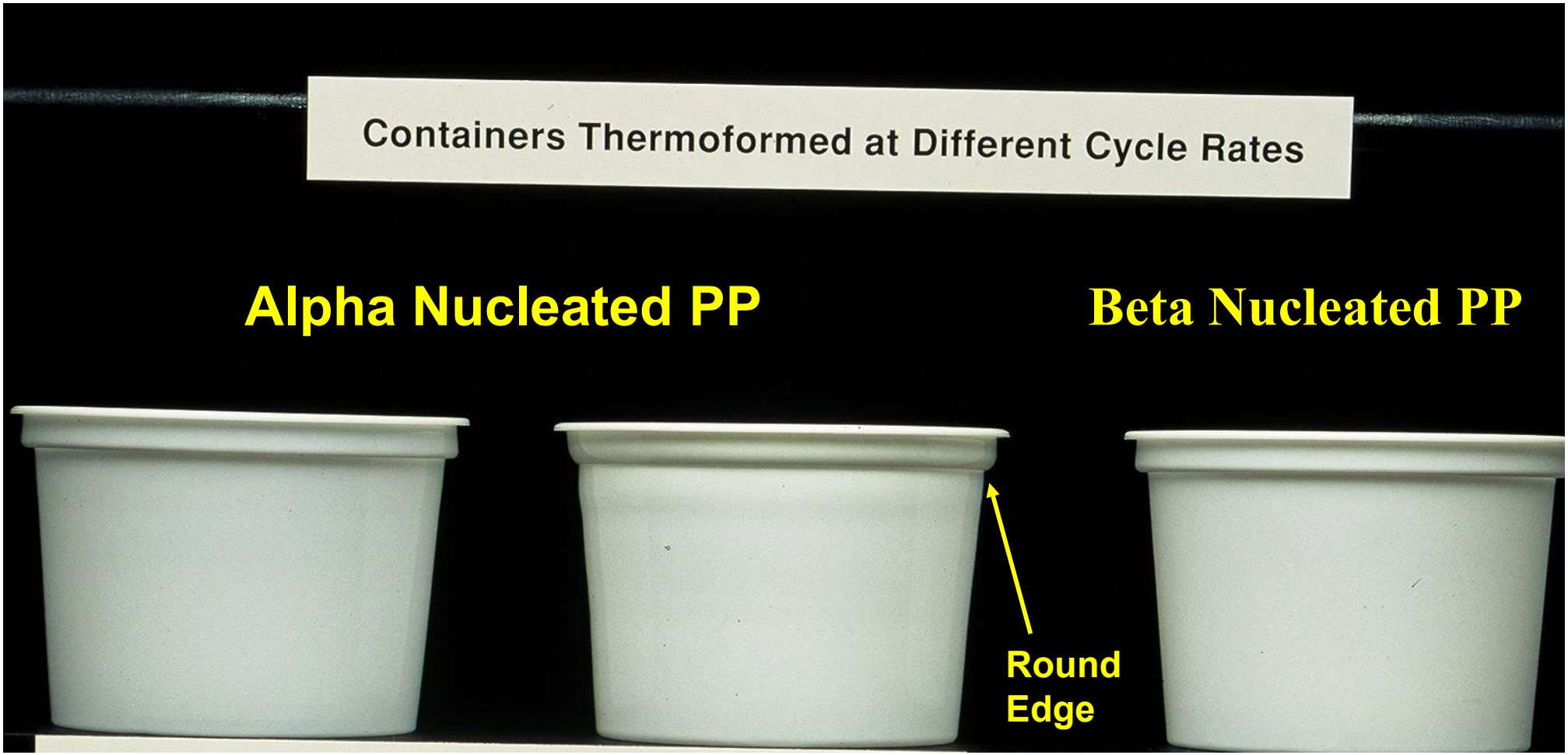


# High Temperature Dimensional Stability of Beta vs Alpha Nucleated PP




**Beta Nucleated** **Alpha Nucleated**

# Effect of Cycle Time on Part Definition For Alpha and Beta Nucleated PP Containers




| 14.9 CPM | 16.6 CPM | 18 CPM |
|---|---|---|
| (standard conditions) | (unacceptable) | (20% Increased Cycle rate) |

# Advantages of Mayzo Beta Nucleation Technology in the Thermoforming of PP

- Broader processing window
- Less sag with no change in melt rheology
- Lower sidewall density (lighter weight)
- White appearance without pigments
- Better material distribution and better crush strength which lead to 15% down-weighting of the final part
- Faster cycle times (up to 25% higher productivity)
- Improved High Temperature Dimensional Stability

# Sustainability Benefits and Reduced Carbon Footprint

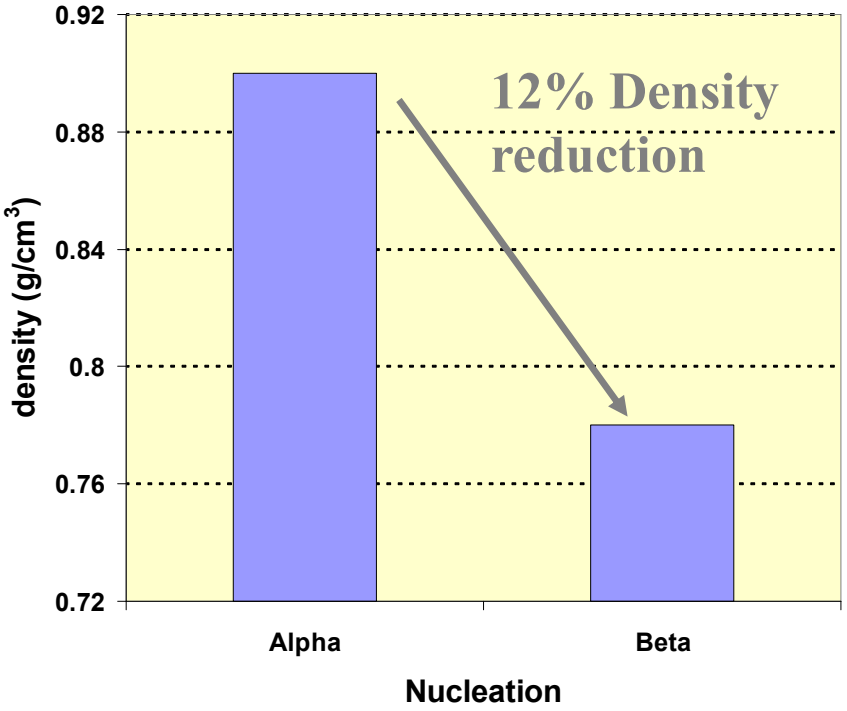
- **Less plastic usage** with no loss in product function
- **Less energy consumed** during production of packaging
  - 25% higher productivity means more output per hour of machine time
  - Lower thermoforming temperatures lead to less energy use
- **Less energy used in transportation** of final product due to lighter package weight
- **Improved recyclability** since little or no white pigment ($TiO_2$) is used to make white containers, and the beta nucleation of the PP resin produces improved mechanical properties (higher impact strength) in products made from the recycled resin
- **Lower Costs!** More **"Green $"** in the pocket of the packaging producer and the food company

# Oriented Microporous Film

# Beta Nucleation in Oriented PP Film


α β

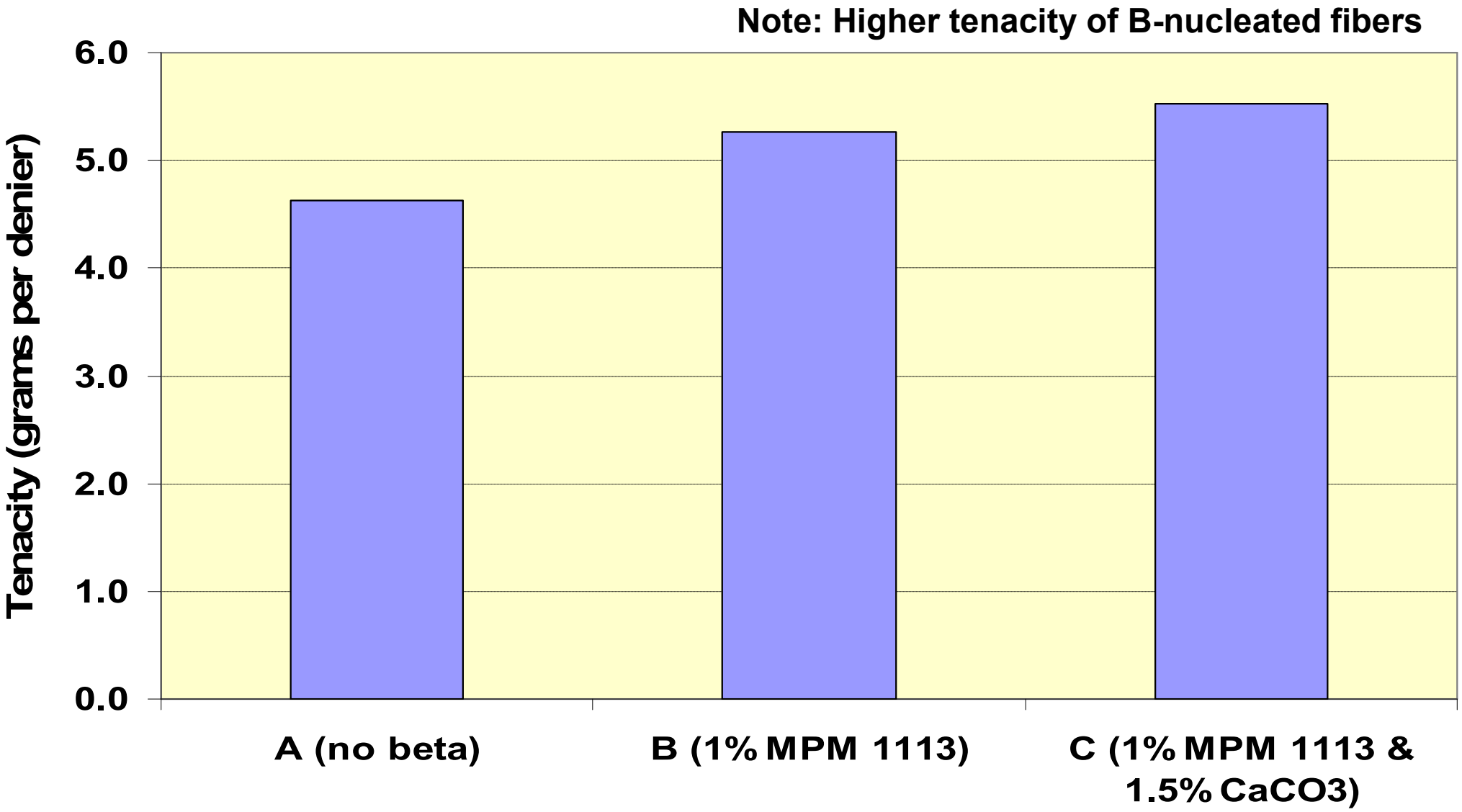

**Monoaxially Oriented PP Film**




## Carpet Backing Tapes

- Higher Tenacity
- Higher yield (more $m^2$ per kg)
- Delustered without fillers

# Tenacity of Carpet Backing Tapes

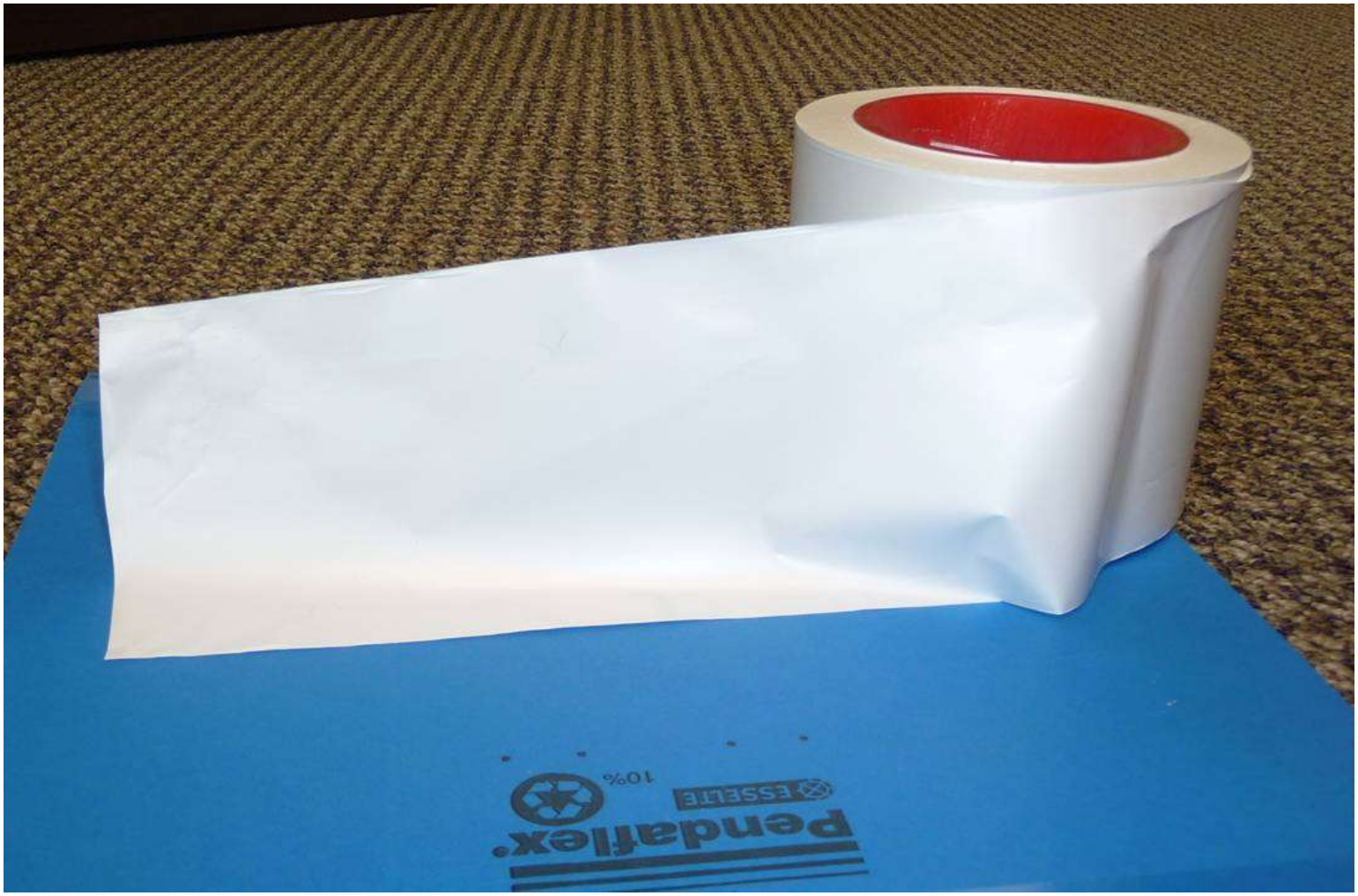


# Applications For Breathable-Waterproof Microporous Film

The Evolving Protective Apparel Market

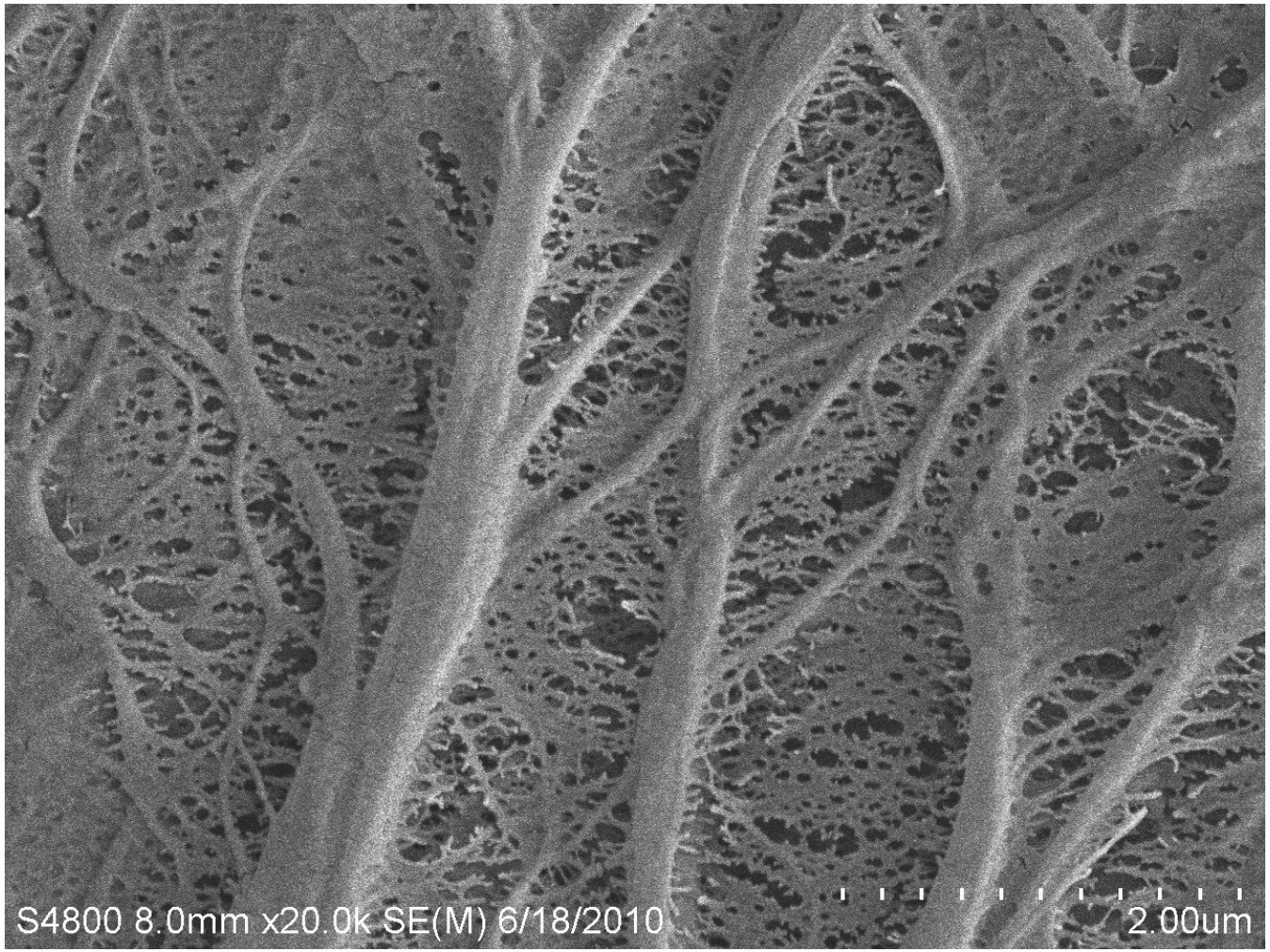
- **Chemical/Medical Protective Suits (**films pass Viral Penetration and Blood Borne Pathogen Tests (ASTM F1671 and ASTM F1670)
- **Roofing Membranes**
- **Car Covers, and car protective films**
- **Lithium Ion battery separator membranes**

# Beta Nucleated BOPP Film for Li-Ion Batteries and Supercapacitors




**Film Thickness: 22 microns  Film Density: 0.28 g/cm$^3$**

# SEM Micrograph of Beta Nucleated Battery Separator Film

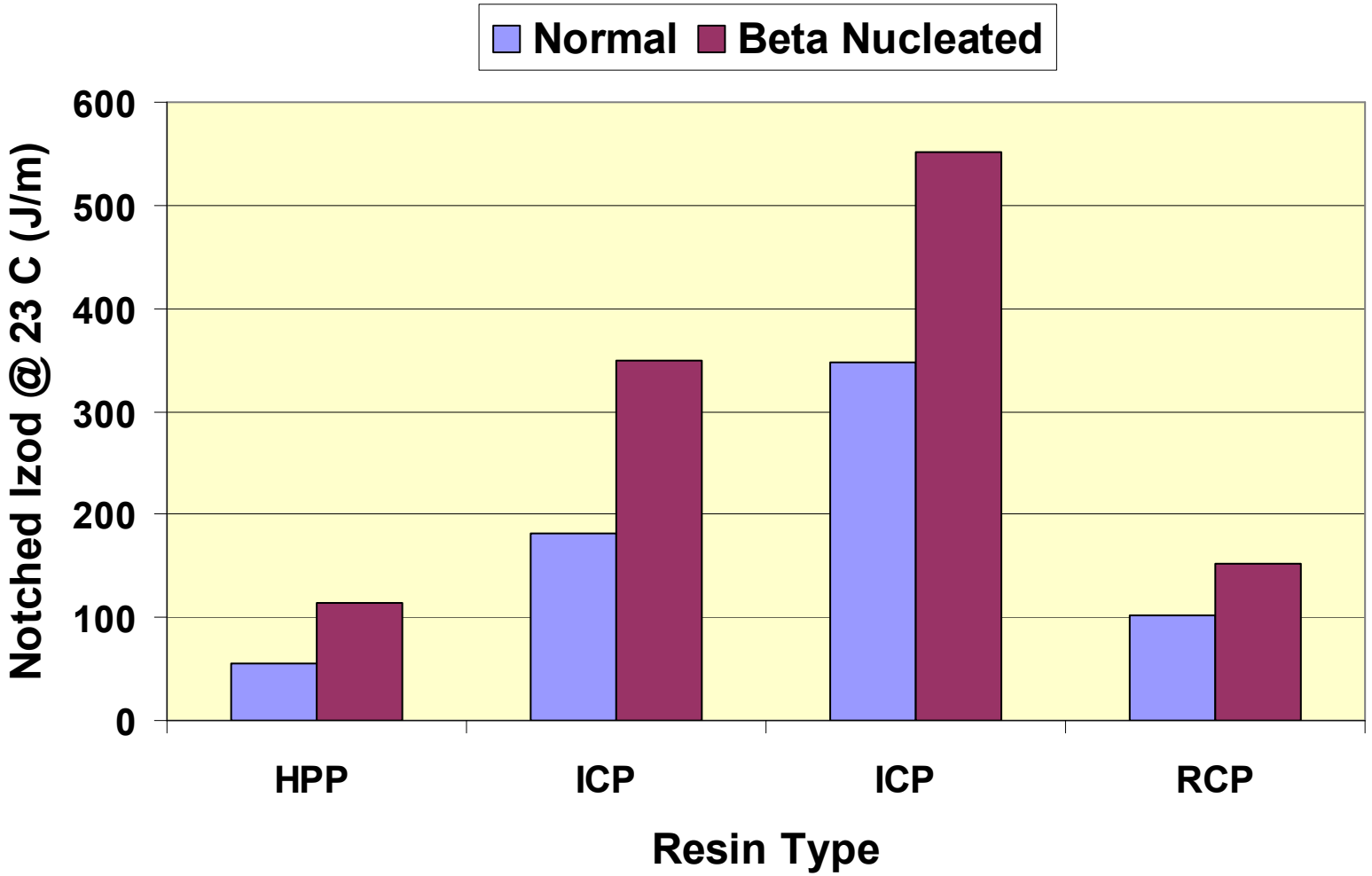


# Advantages of Beta Nucleation in the Production of Microporous Films

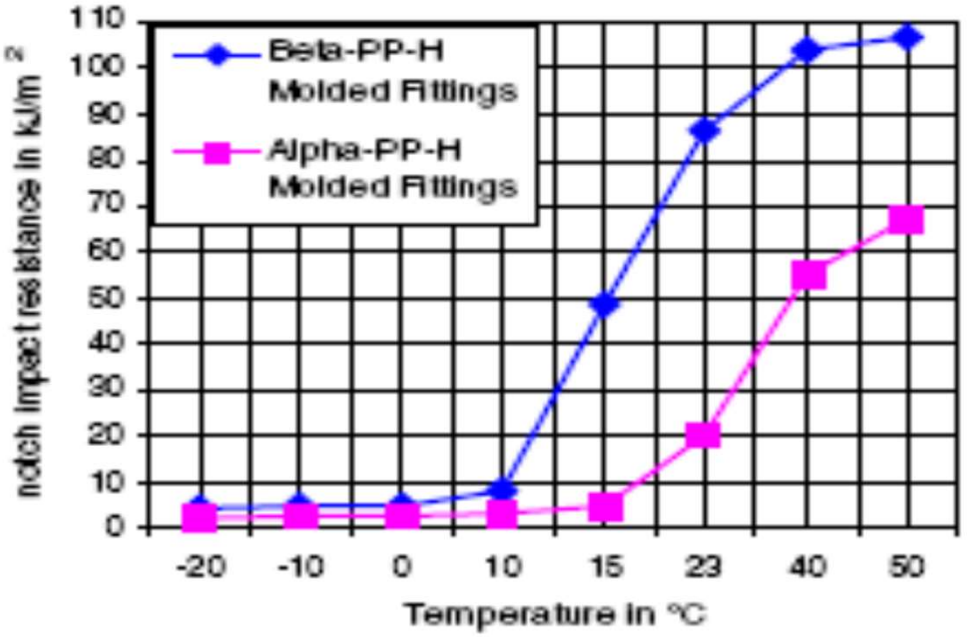
- Production of white, low density microporous films without the use of fillers or pigments
- Improved printability
- Extremely low density films with high breathability can be produced in the BOPP process. Can be used in protective clothing, construction applications, and as separator membranes in Li-ion batteries and supercapacitors
- Produces high tenacity, delustered carpet backing fibers (patent pending)

# Impact Improvement

# Using Beta Nucleation to Improve the Impact Strength of PP



# Ductility and Impact Strength

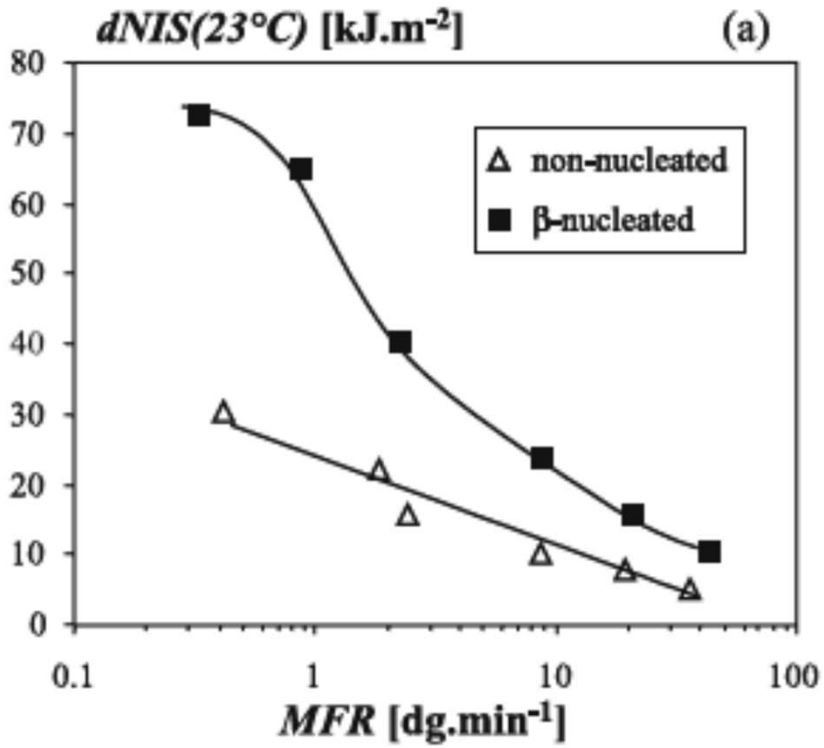


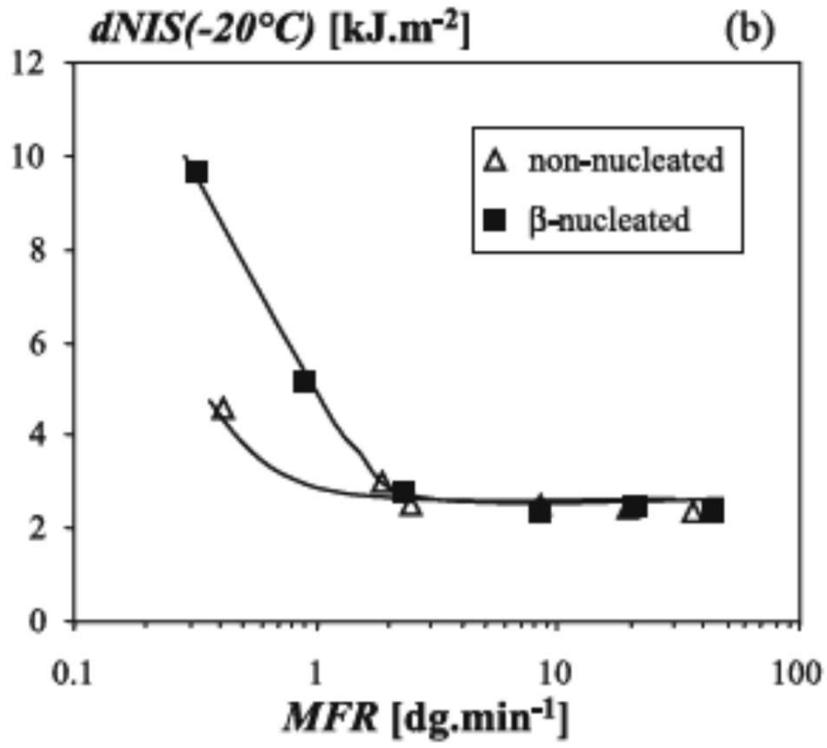

**Note dramatic improvement in impact strength above 0 °C**

## Injection Molded ASTM Properties

| Property | β-Nucleated | Non-Nucleated |
|---|---|---|
| | | |
| MFR (g/10 min) | 3.2 | 3.3 |
| Yield Strength (psi) | 4350 | 4976 |
| Yield Elong. (%) | 11.0 | 8.9 |
| Flex. Modulus (psi) | 213,520 | 212,170 |
| Notched Izod @23 °C (ft-lbs/in) | 3.23 | 0.78 |

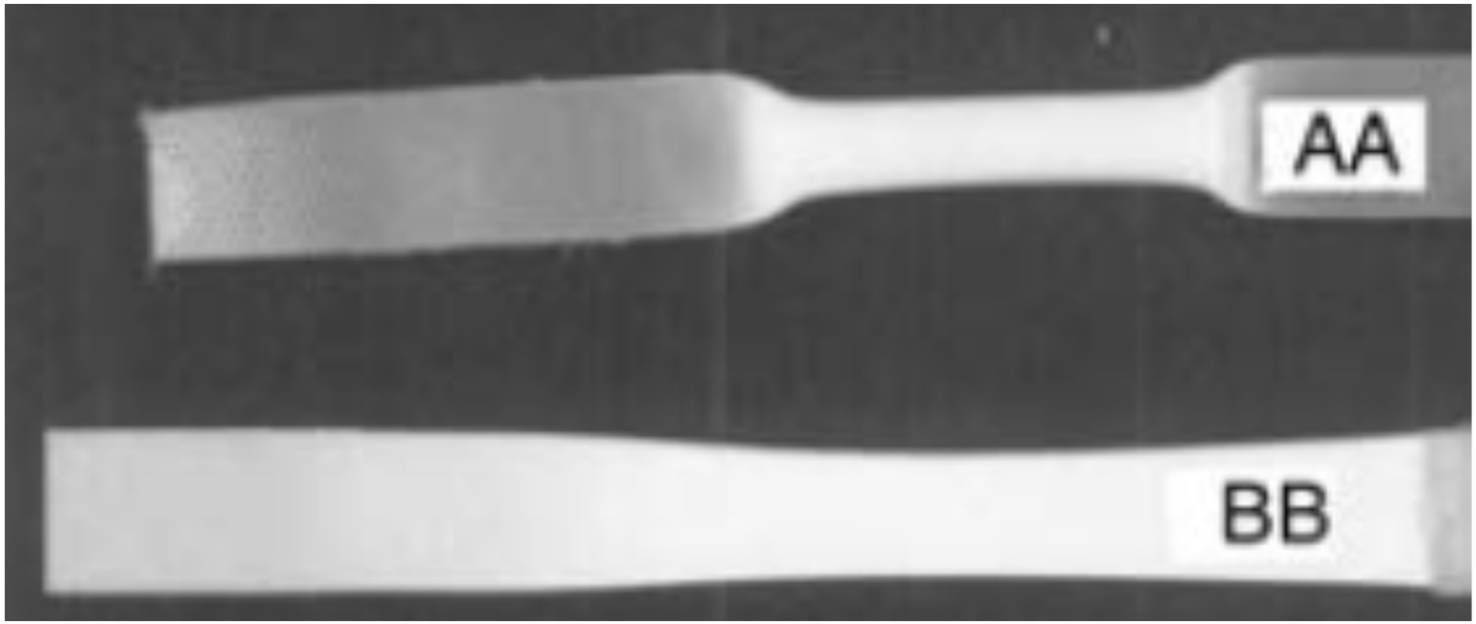
# Effect of Molecular Weight and Temperature on the Impact Strength of Beta Nucleated PP



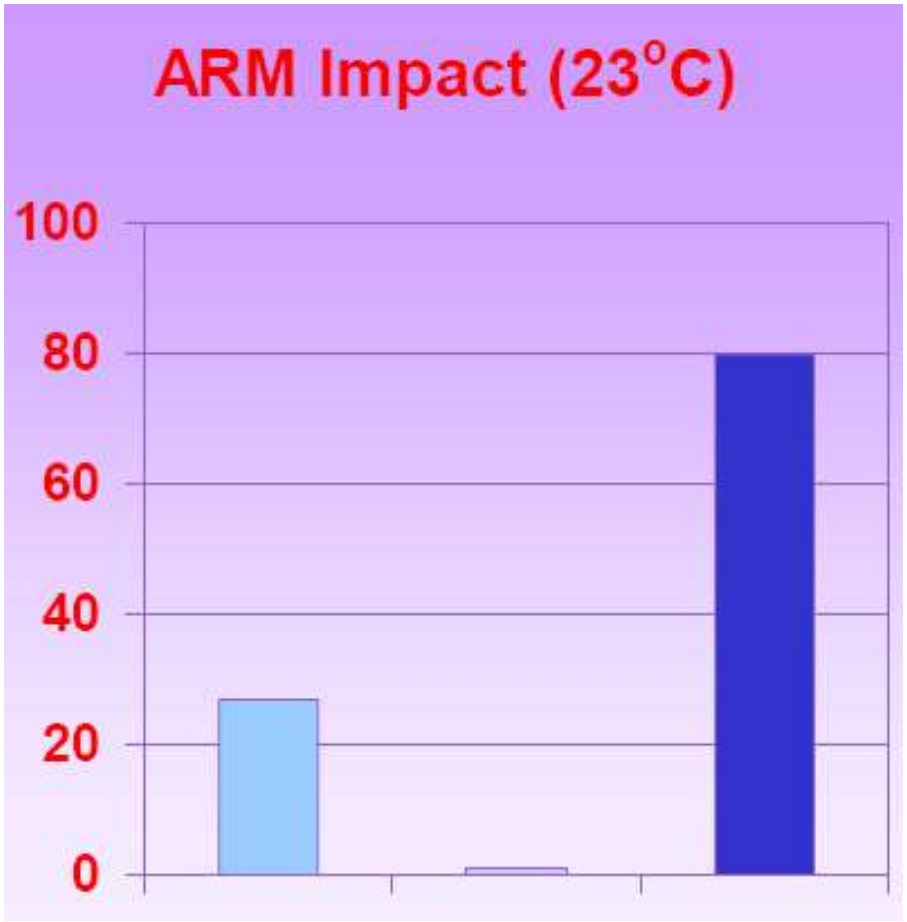

Double Notched Impact Strength (dNIS) vs log(MFR) for beta & non-nucleated PP at 23 C and -20 C

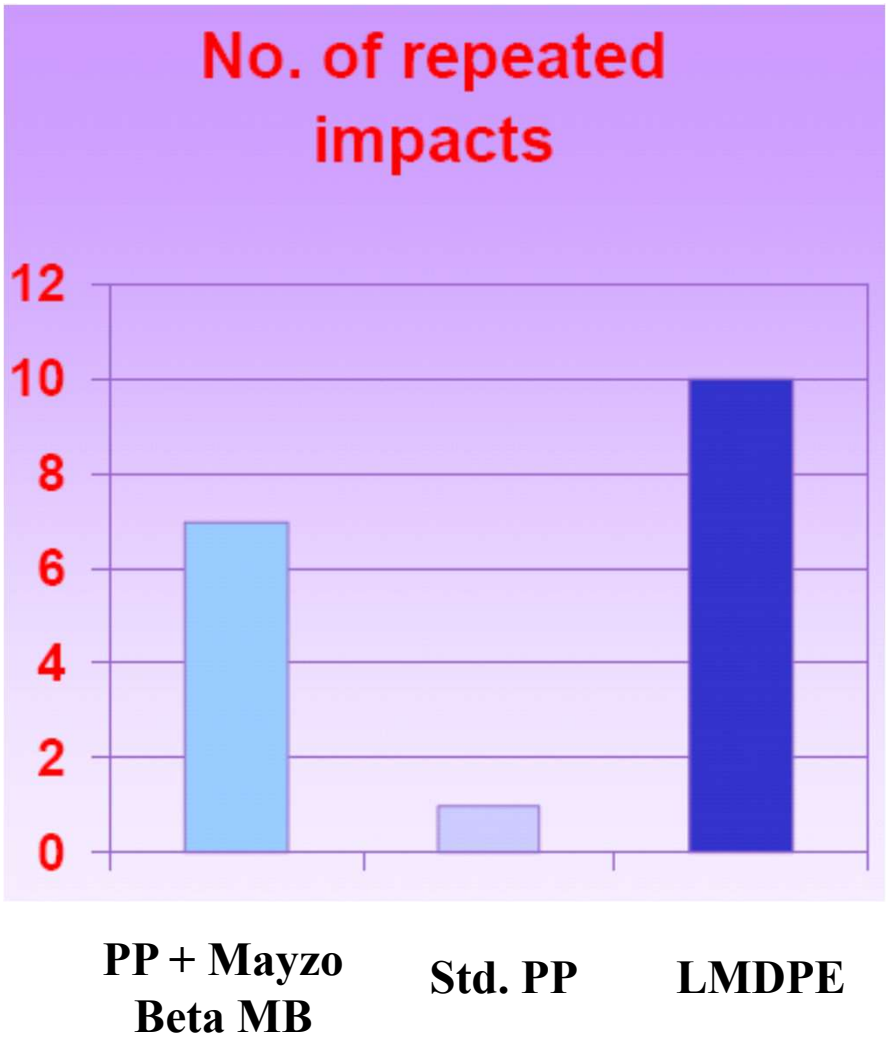
# Drawn Tensile Specimens of Alpha (AA) and Beta (BB) Crystalline PP




Note more uniform orientation in β-nucleated PP test bar

# Impact Enhancement in Rotomolded PP

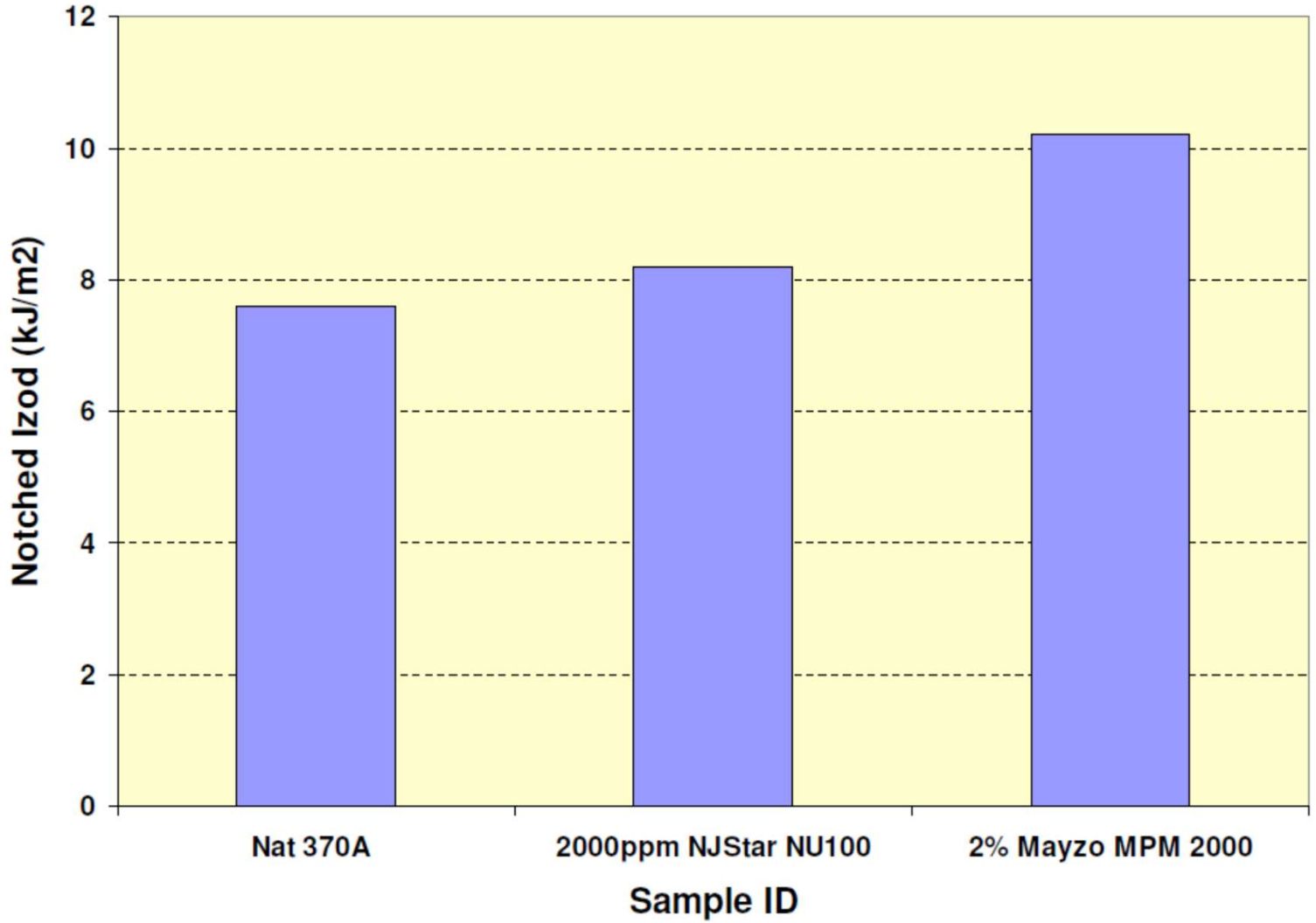


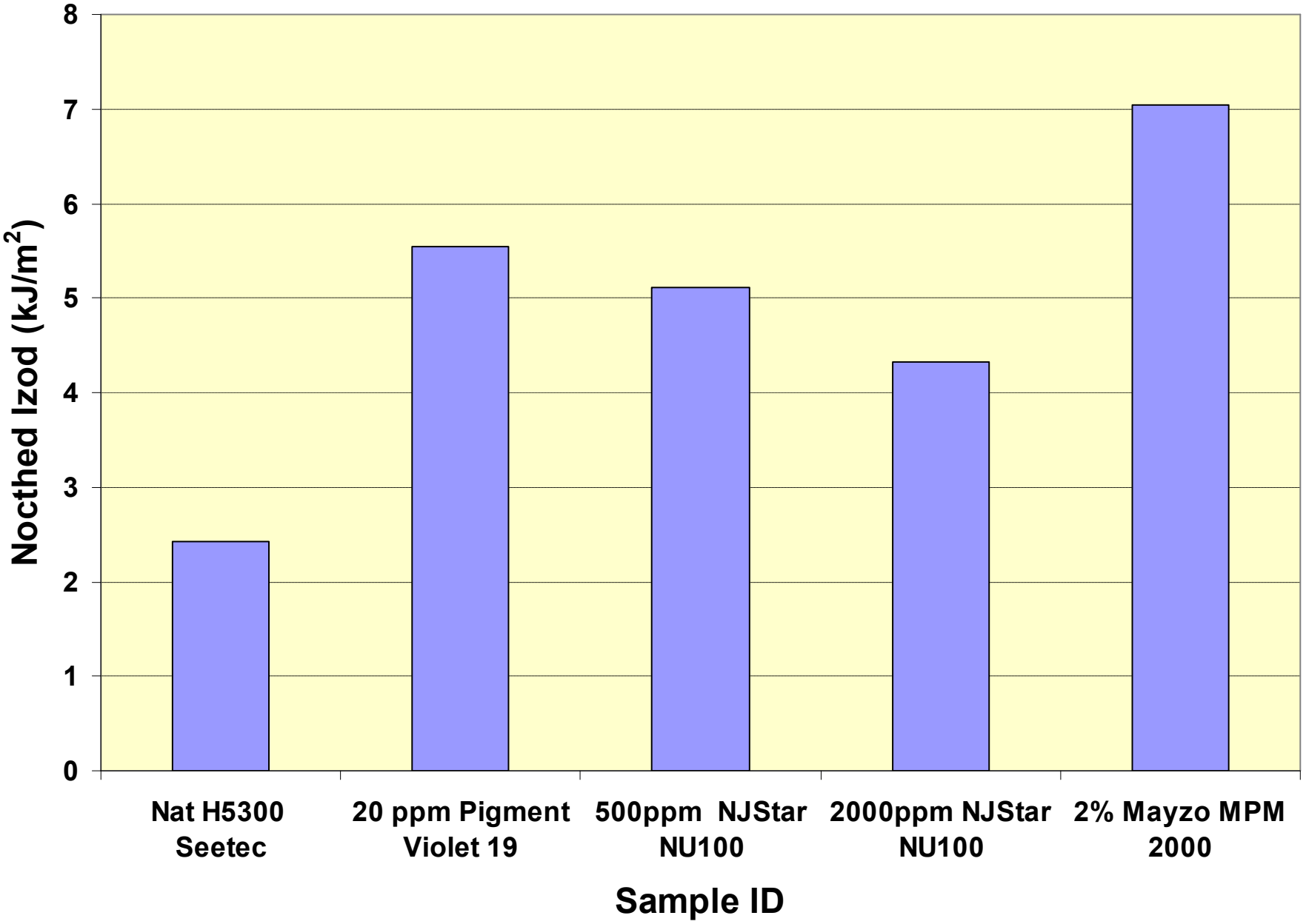
# Properties of Non-Nucleated & β-Nucleated PP Homopolymer with 0.3% MPM 2000

| Property | β-Nucleated | Non-Nucleated |
|---|---|---|
| | | |
| MFR (g/10 min) | 3.2 | 3.3 |
| Yield Strength (psi) | 4350 | 4976 |
| Yield Elong. (%) | 11.0 | 8.9 |
| Flex. Modulus (psi) | 213,520 | 212,170 |
| Notched Izod @23 °C (ft-lbs/in) | 3.23 | 0.78 |

# Notched Izod Impact of 20% Talc Filled PP ICP with and without β-nucleants



# Notched Izod Impact of Beta Nucleated PP Homopolymer Compounded on Twin Screw



# Impact Strength Improvements Using Beta Nucleation

- Beta nucleation leads to dramatically higher impact strength improvements with only small losses in flexural modulus
- Beta nucleation allows PP to be used in rotomolding applications without the extreme brittleness normally seen in this application
- Mayzo's new 3rd generation beta masterbatch, MPM 2000, can be used at very low addition levels to achieve these benefits

# Limitations of Using Beta Nucleation in Alpha Nucleated PP

- Alpha nucleants generally prevent beta crystal formation
- Many PP resins are alpha nucleated to increase modulus, reduce cycle time, and improve clarity
- Common additives such as certain pigments and talc are also alpha nucleants
- When both alpha and beta nucleants are present in the resin, very little or no beta crystals are produced
- The high activity MPM 2000 will work in the presence of weaker alpha nucleants such as sodium benzoate and talc

# Mayzo Product Offerings

**MPM 2000:** 3rd generation MB, white pellets. 0.5% - 1.0% addition in non-nucleated PP resins. Works in some alpha nucleated PP resins containing talc or sodium benzoate, but higher addition levels may be required.

# Overall Conclusions

- Beta Nucleation can be used in a variety of applications to improve properties such as impact strength, drawability, thermoformability, and creep rupture performance (pressure pipes)
- The unique drawing characteristics of the beta crystal phase result in more uniform wall thickness distribution in thermoformed PP and biaxially oriented geogrids allowing for improved down-weighting and cost savings
- The production of microvoids, which takes place when beta nucleated PP is drawn in the solid state, allows for the production of microporous films which are used in construction and apparel applications, and in the production of separator membranes for lithium-ion batteries