Imagine working with a company that has no boundaries on exploring solutions for

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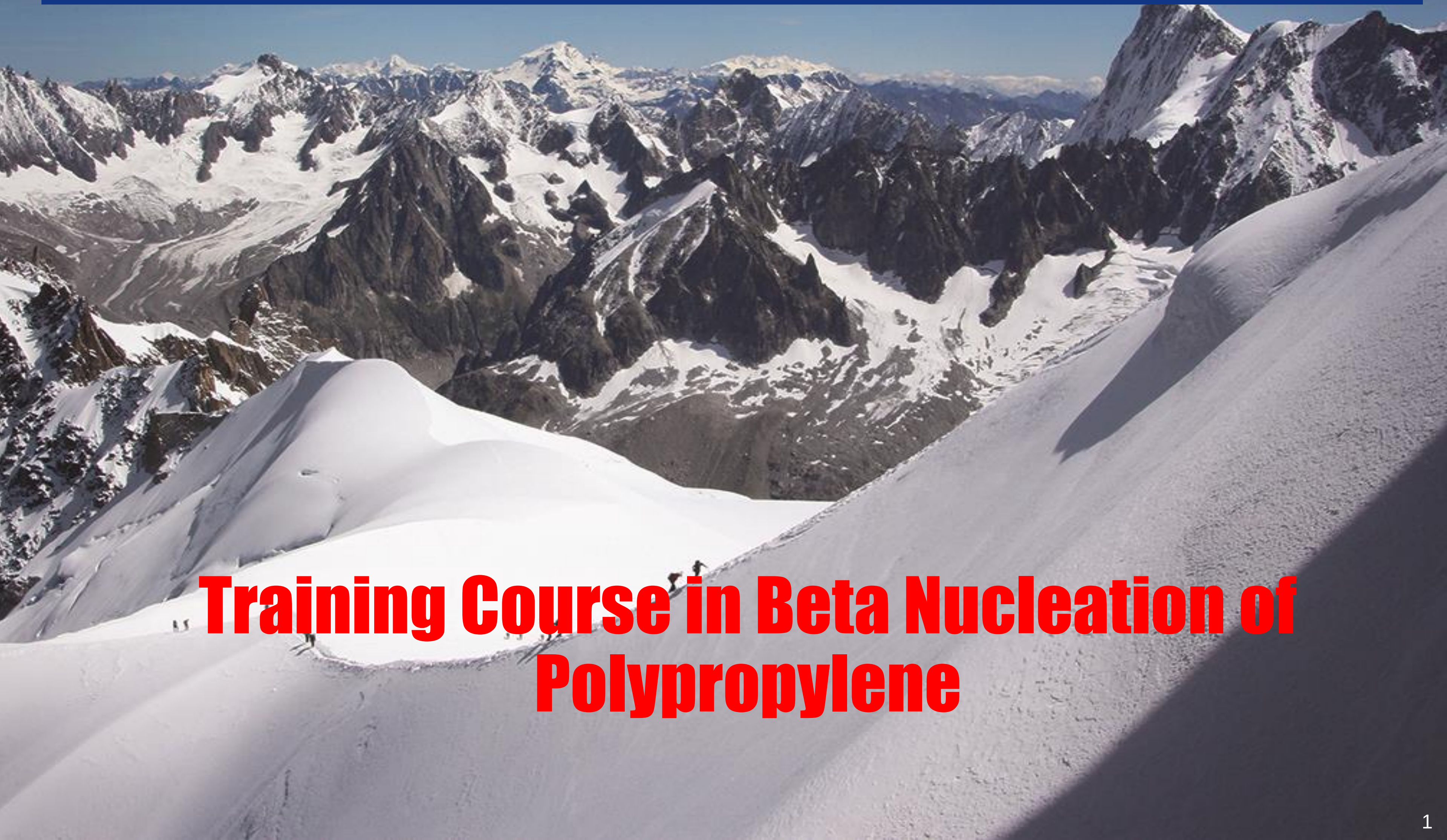

Training Course in Beta Nucleation of Polypropylene

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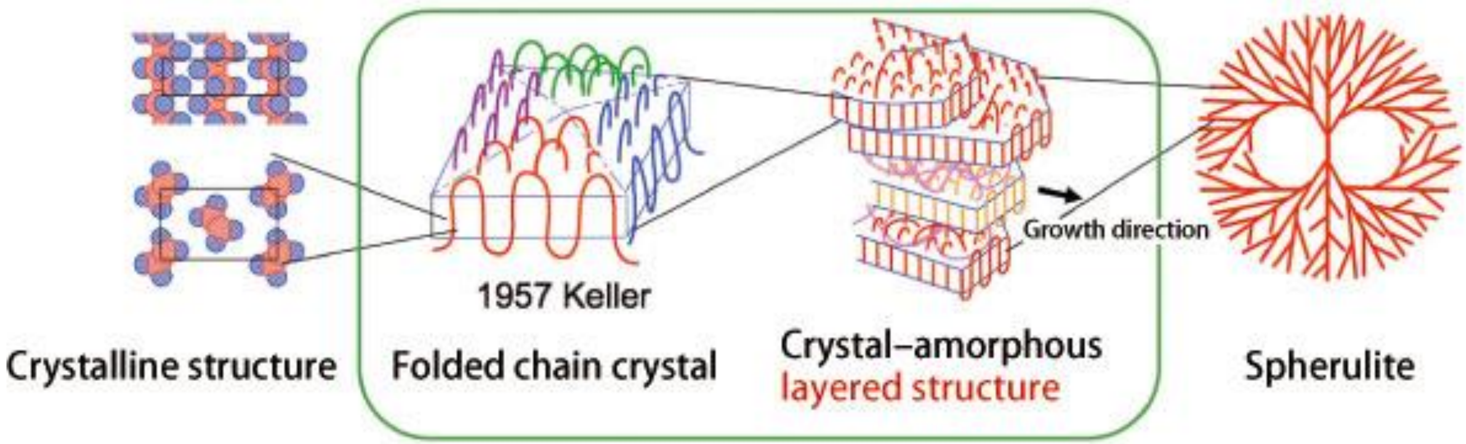
Outline

- Crystal morphology of PP
- Nucleation of PP
- Conditions required to produce α & β crystal phases
- Differences between Alpha & Beta crystals
- Unique properties of the β crystal phase
- Applications using beta nucleation
  - Geogrids
  - Oriented film
  - Thermoforming
  - Injection molding
  - Rotomolding

Crystal Morphology of PP



Microstructures that form during polymer crystallization

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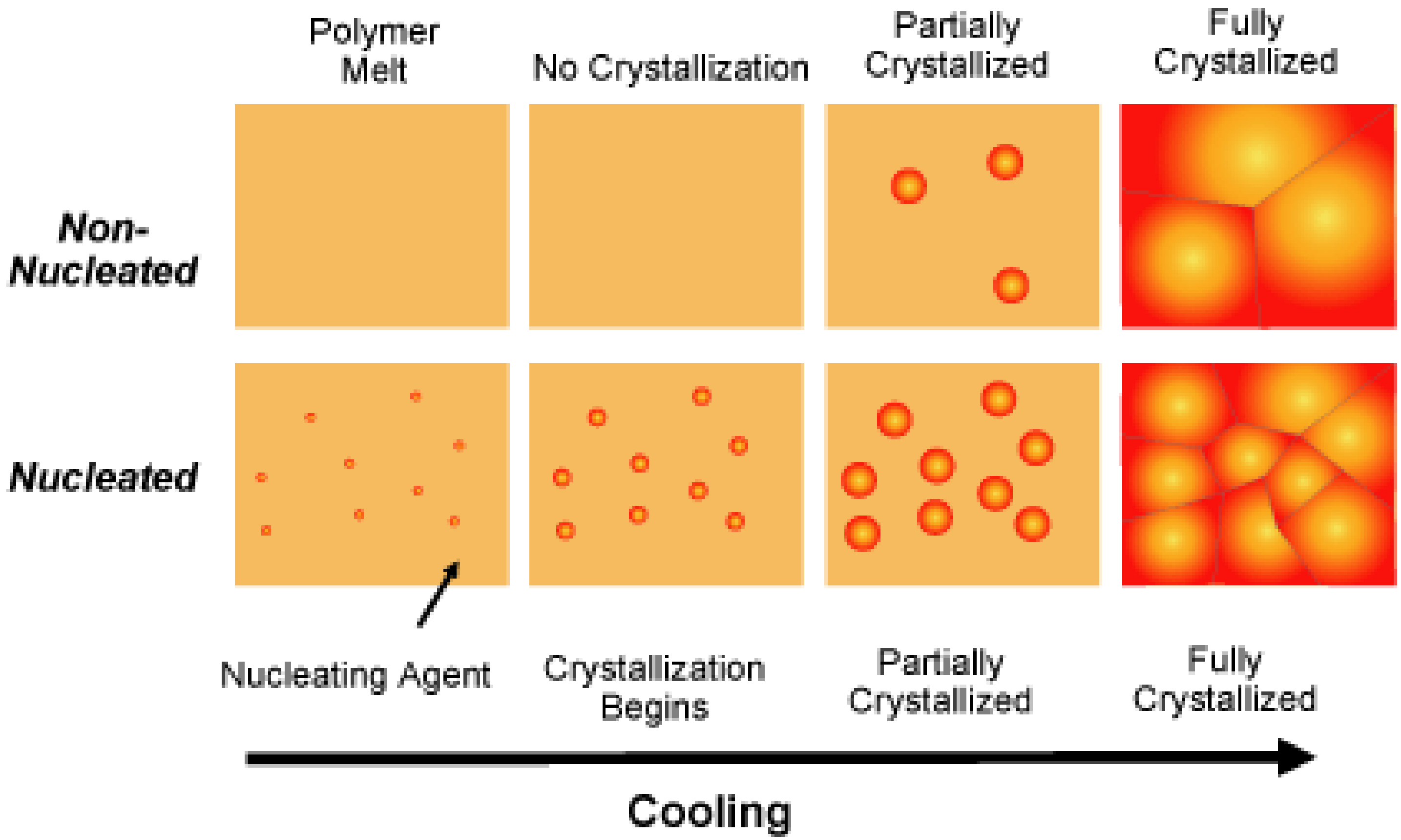
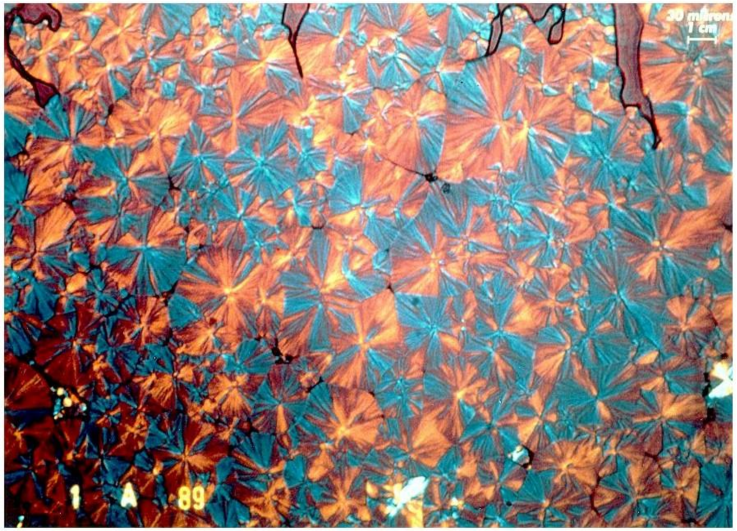
The Effect of Nucleating Agents in Polypropylene

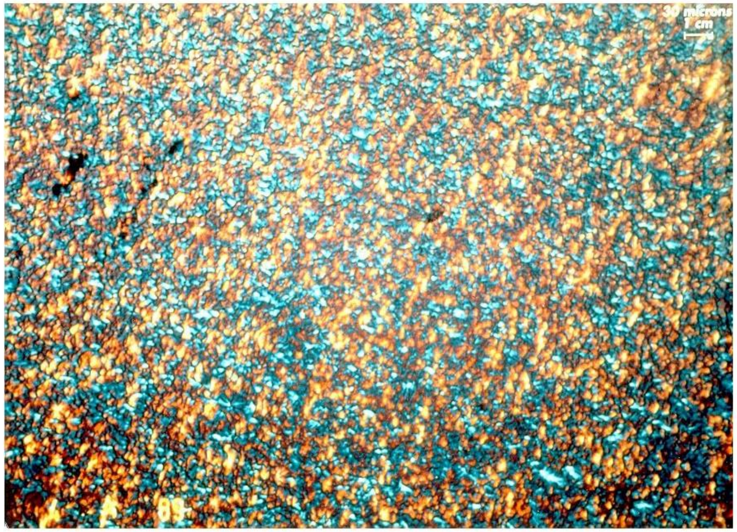


Spherulite Morphology

Spherulitic Structure of PP seen under crossed polars



Non-nucleated



Nucleated

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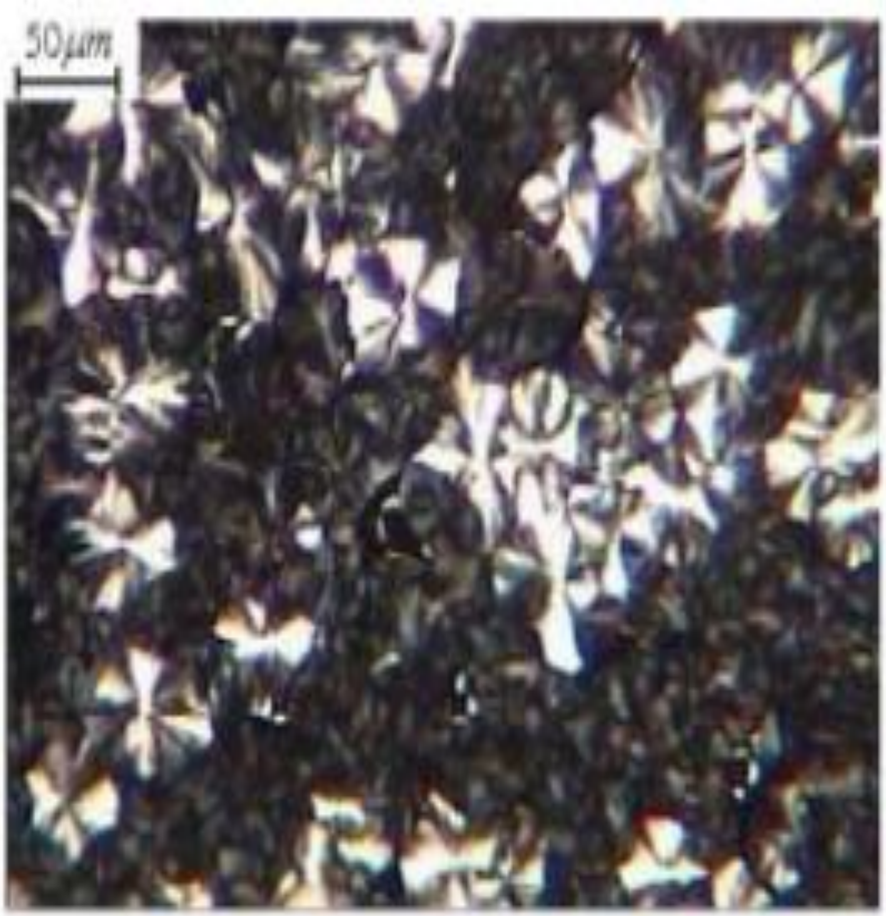
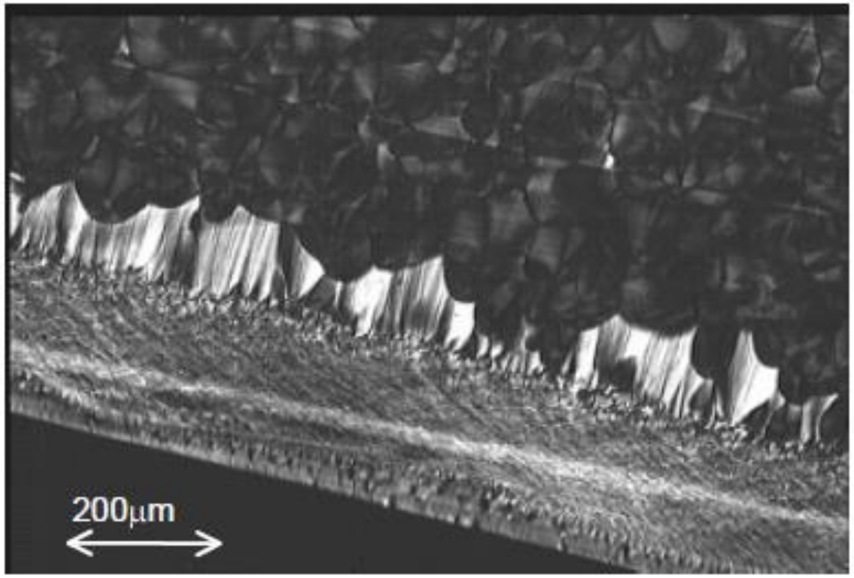
Mixtures of Alpha & Beta Spherulites

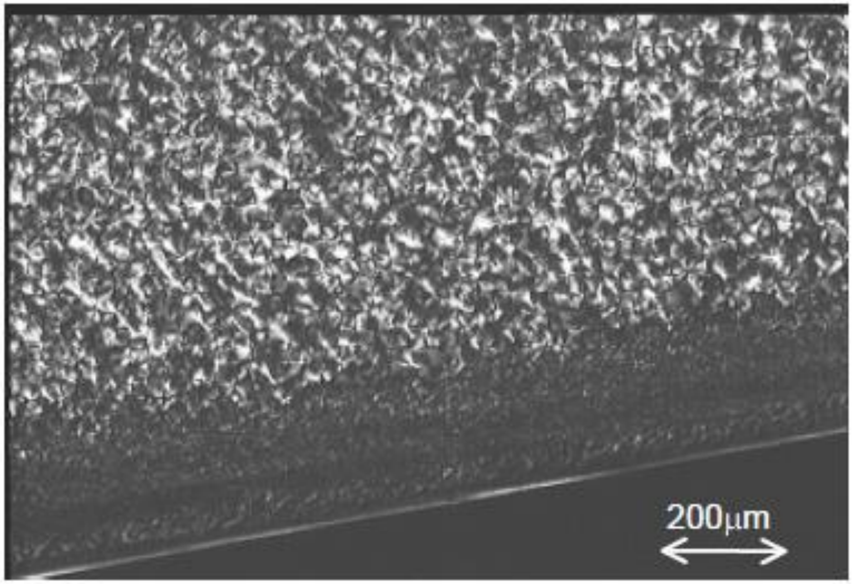


Viewed under Crossed Polars

Chromic Acid Etched Surface of PP using Scanning Electron Microscopy (SEM)

Skin-Core Morphology of Injection Molded PP





Non-nucleated PP

Beta Nucleated PP

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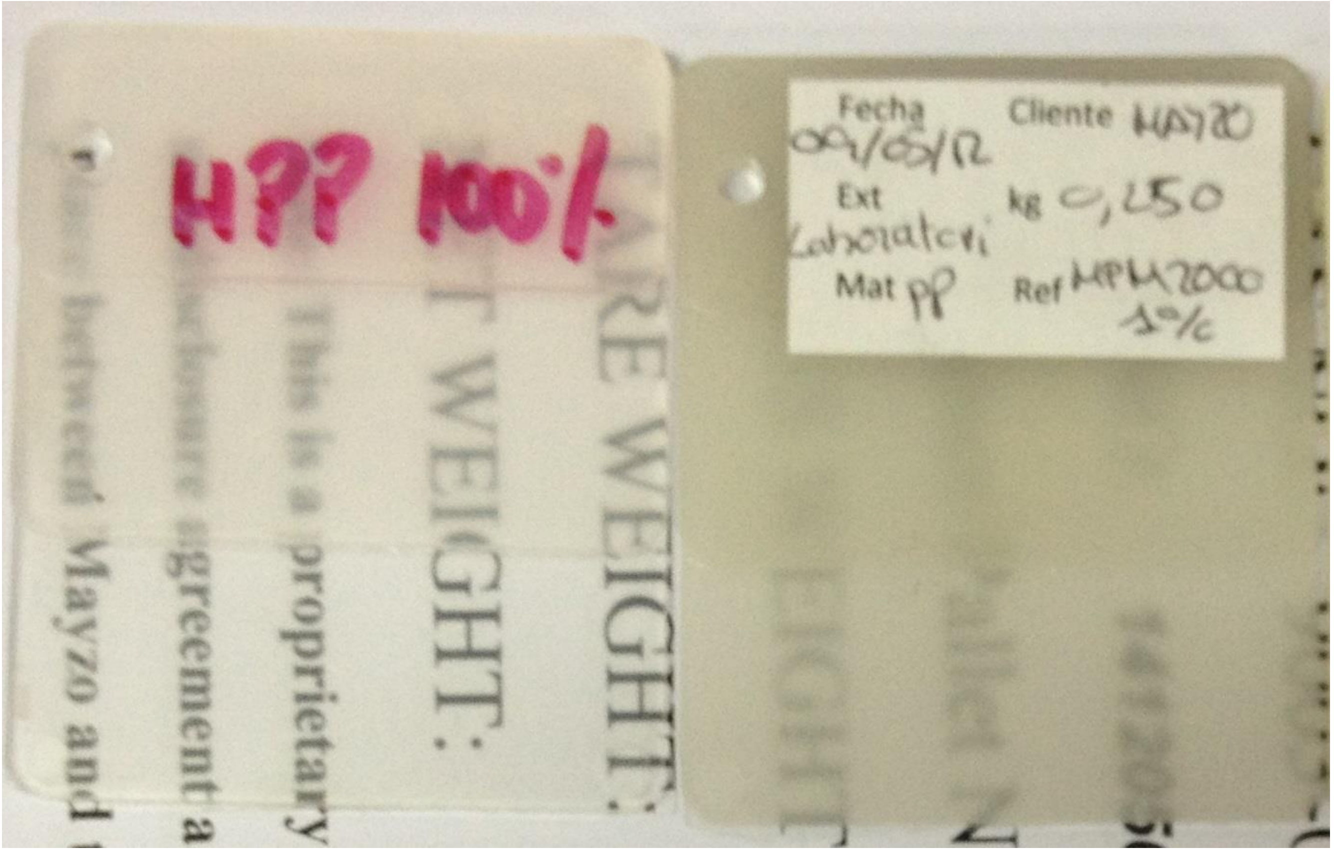
Transparency of α & β Crystalline PP



Alpha PP Beta PP

DSC Melting Curves for Alpha and Beta PP

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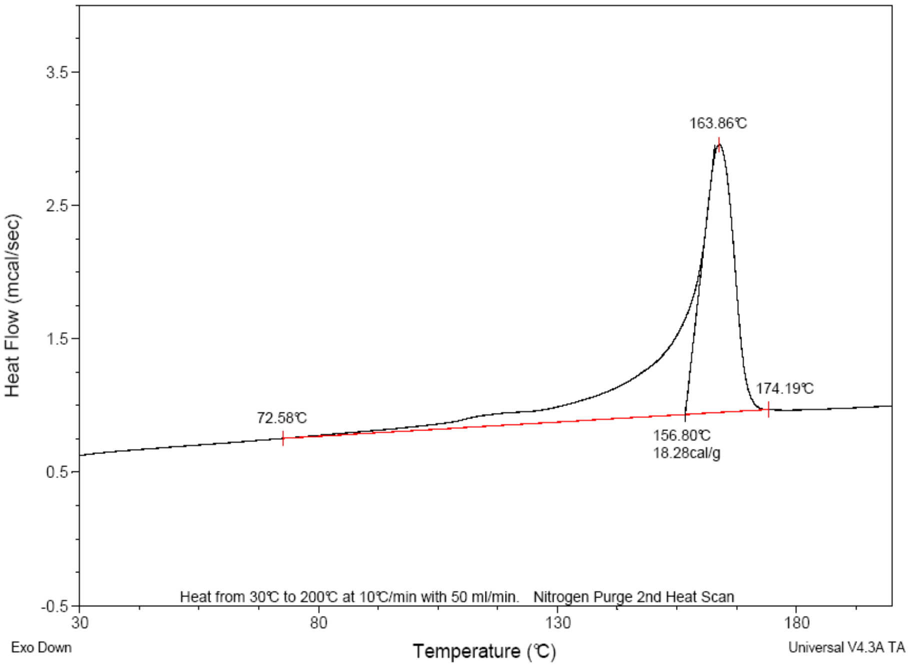
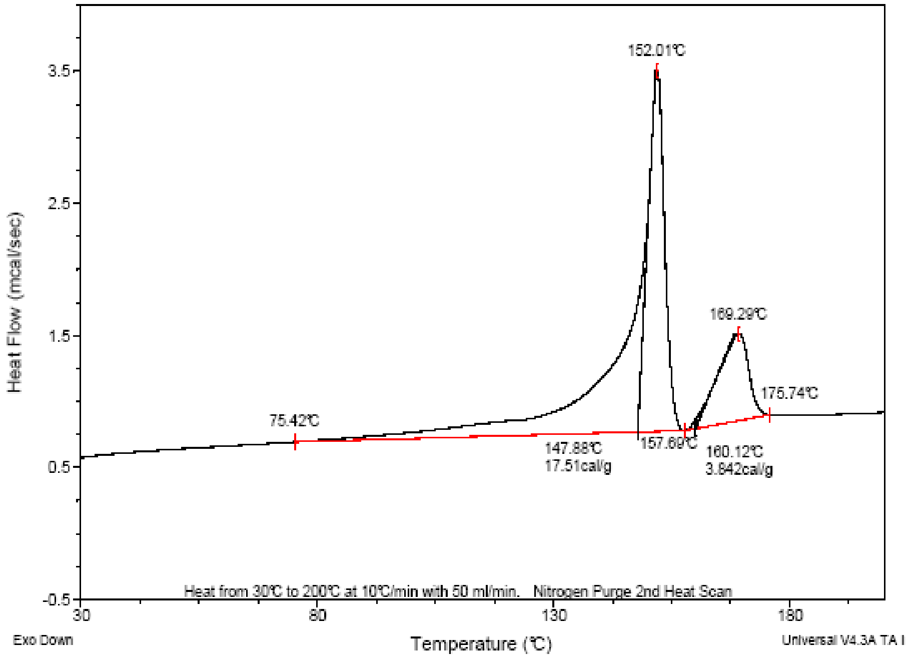
Alpha PP



Beta PP



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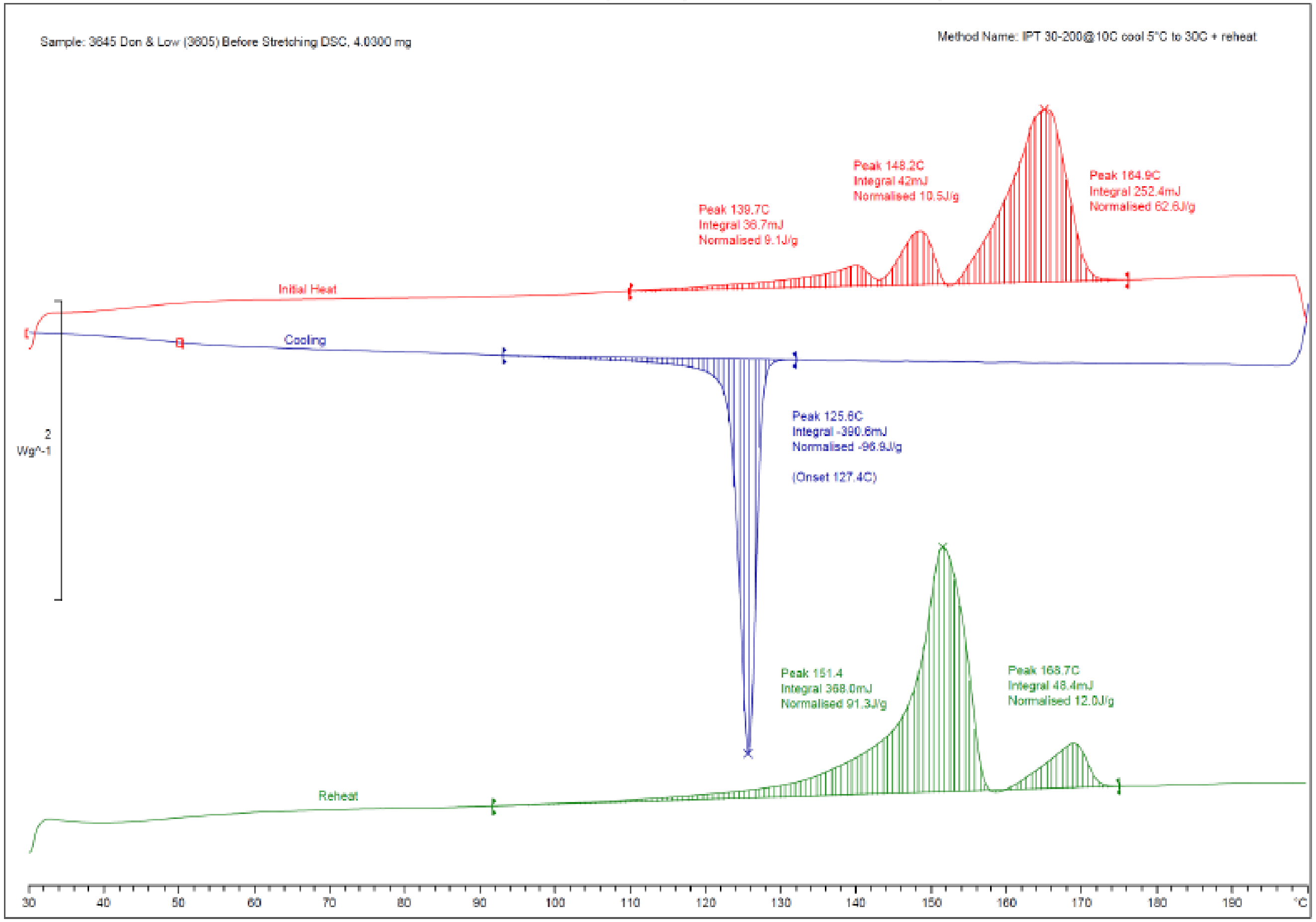
Heat-Cool-Heat DSC Scans



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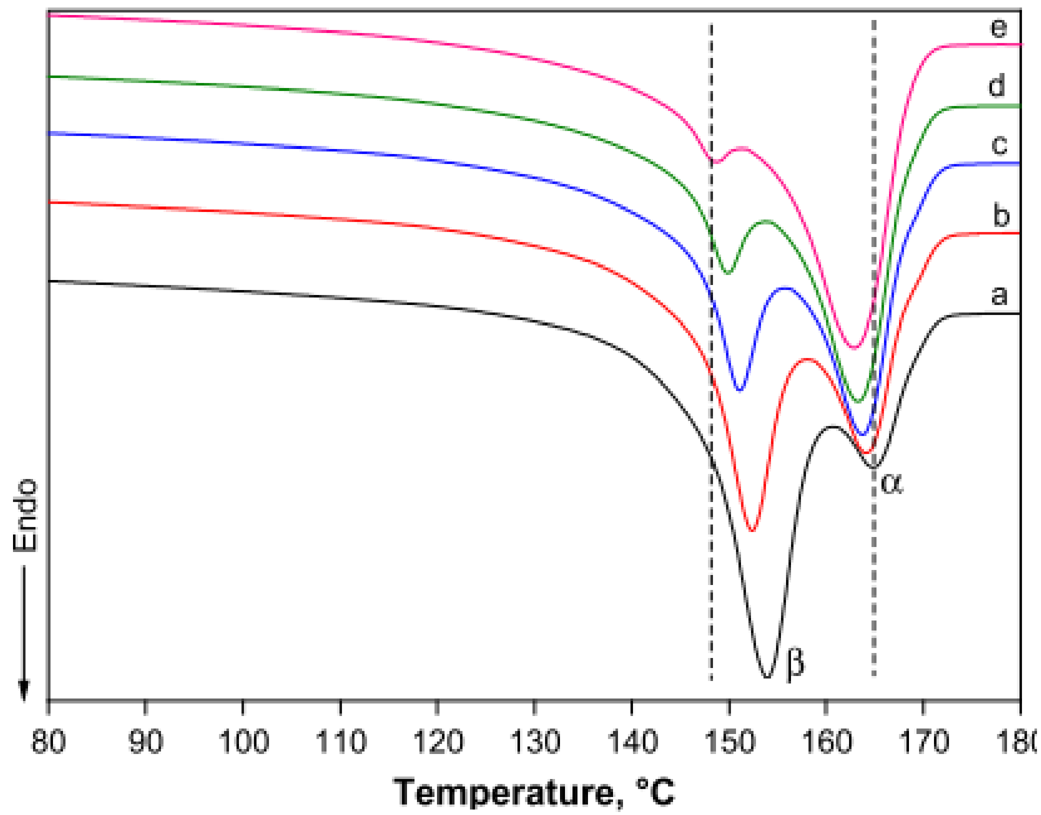
Conditions Required to Produce High Levels of Beta Crystallinity

1. Presence of a beta nucleant
2. Crystallization under high shear conditions
3. Crystallization in a thermal gradient
4. Crystallization in the temperature range of 90 – 130 ^{o}C

Note: All commercial applications of beta nucleation involve the presence of a beta nucleant and crystallization in the proper temperature range

Effect of Cooling Rate on the Formation of Beta Crystals



DSC melting curves (2nd heat scans) for beta nucleated PP samples crystallized at different cooling rates: (a) 2.5 oC/min, (b) 5.0 oC /min, (c) 10 oC /min, (d) 20 oC /min, (e) 40 oC /min

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Differences Between Alpha and Beta Crystal Phases in PP

Alpha Phase

- Melts at ~ 164 ºC
- Most common phase
- Many nucleants known. Some nucleants are also clarifiers
- Alpha nucleants increase modulus and reduce cycle time
- Nucleants are almost always incorporated into the PP by the resin companies

Beta Phase

- Melts at ~ 150 ºC
- Very few nucleants are known
- More ductile phase – lower forces needed for stretching
- Transforms to alpha phase on stretching
- Undergoes more uniform drawing than alpha phase, and exhibits microvoiding
- Always reduces clarity
- Lowers modulus up to 10%
- Increases impact strength

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Typical Properties of α & β PP

Property	α-iPP	β-iPP
E-modulus [GPa]	2.0	1.8
Yield stress [MPa]	36.5	29.5
Yield strain [%]	~ 12	~ 7
Necking stress [MPa]	27.5	28
Necking strain [%]	~ 22	-
Tensile strength [MPa]	39.5	44
Tensile strain [%]	~ 420	~ 480

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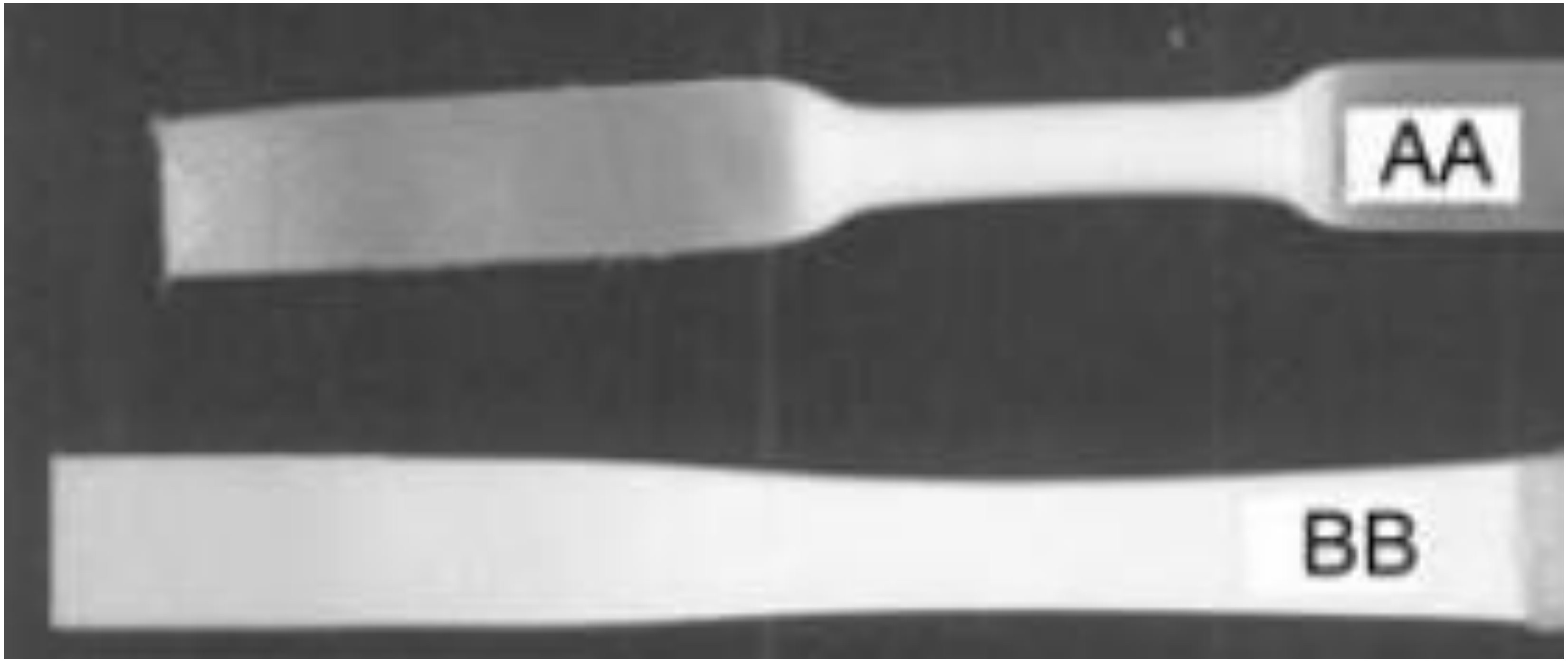
Properties of 3 MFR PP Homopolymer with 0.3% MPM 2000 vs Non-nucleated PP

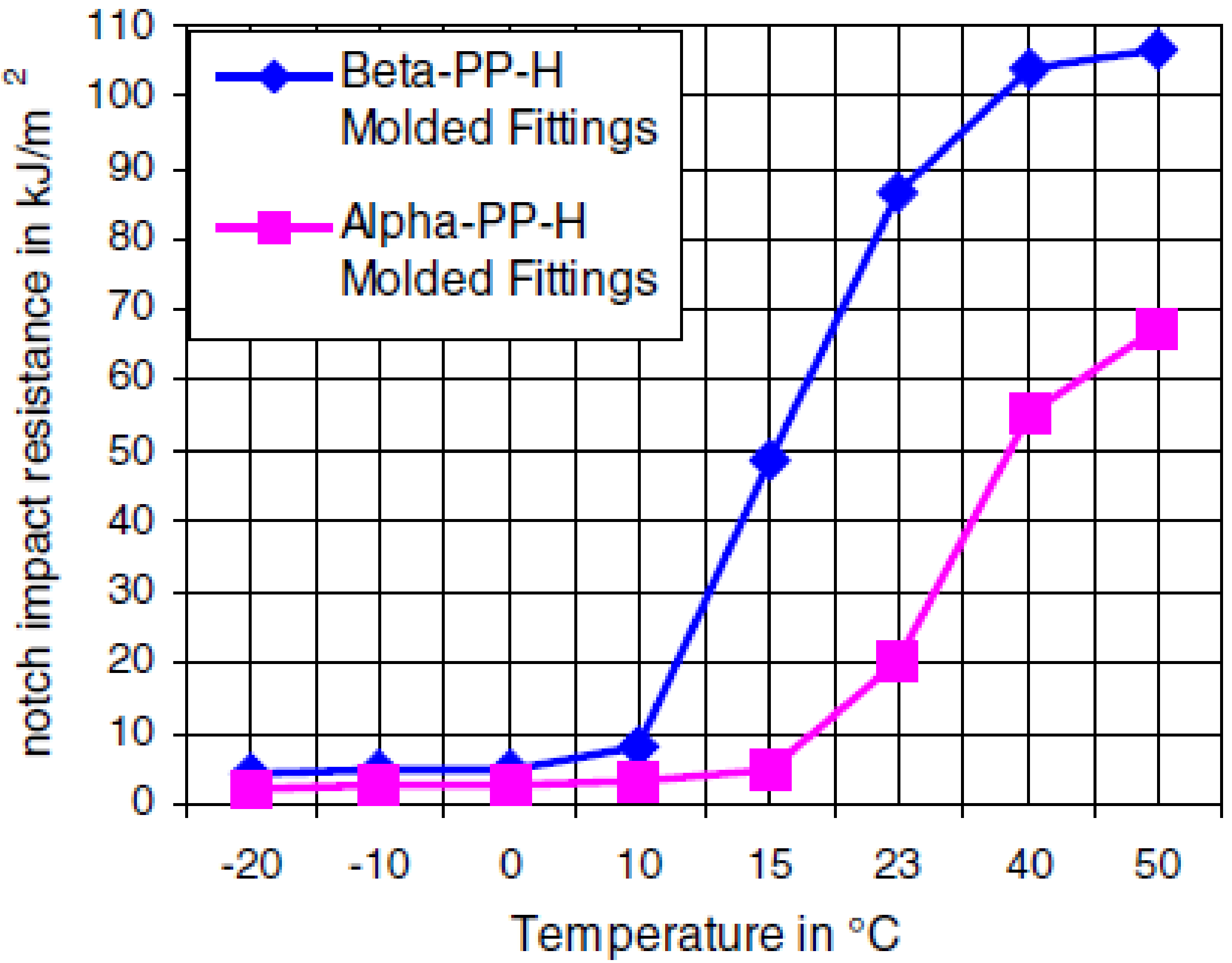
Property	β-Nucleated	Non-Nucleated
MFR (g/10 min)	3.2	3.3
Yield Strength (MPa)	30.0	34.3
Yield Elong. (%)	11.0	8.9
Flex. Modulus (MPa)	1,470	1,460
Notched Izod @23 °C (J/m)	172	42

Effect of Crystal Type on the Necking of PP



AA is Alpha PP and BB is Beta PP

Notched Impact vs Temperature for Alpha & Beta PP



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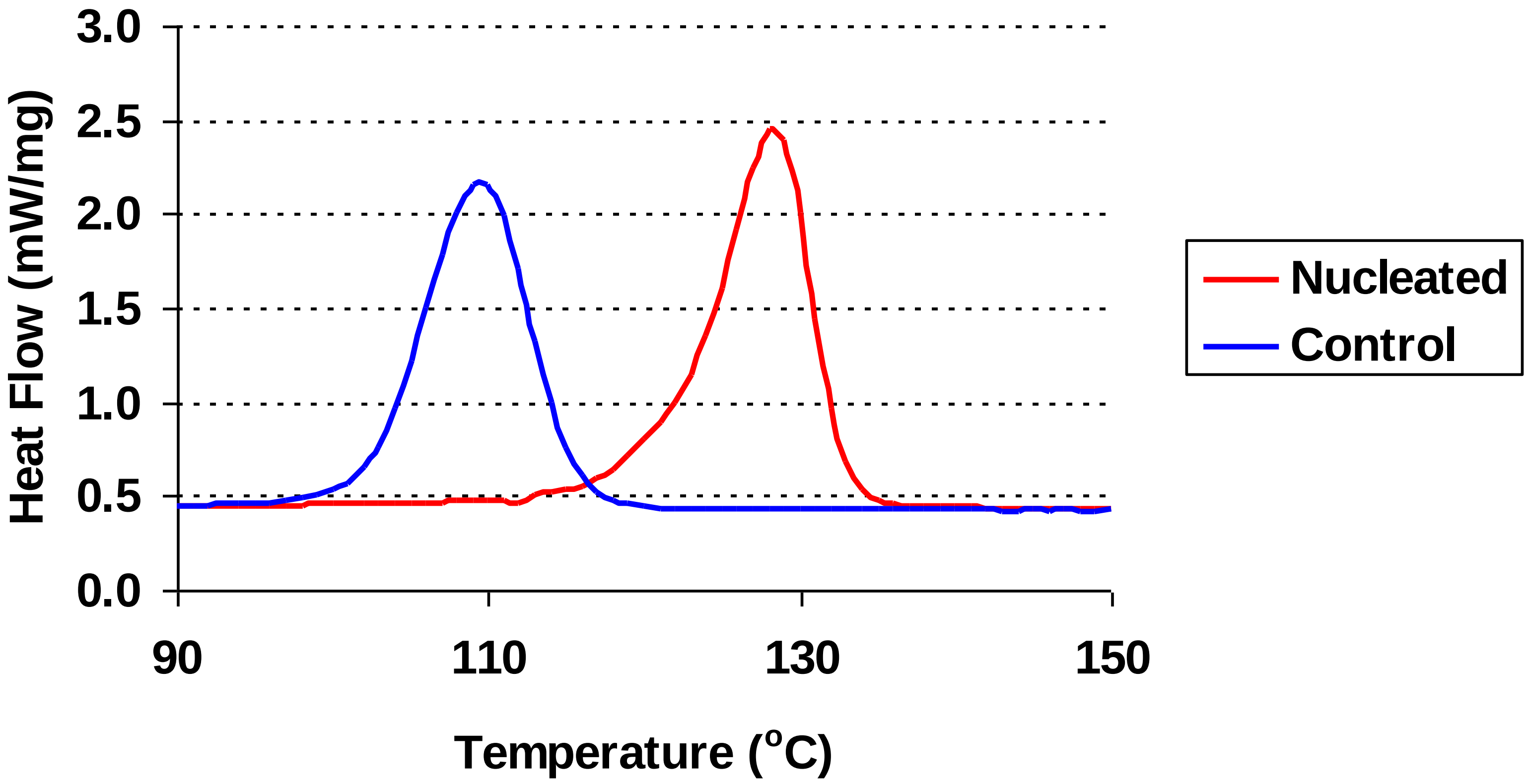
Effect of Nucleating Agent Type on the Crystallization of PP



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Effect of Alpha Nucleant on Tc

Nucleator	Polymer Tc (^{o}C)
None	110 - 114
Sodium Benzoate	122 - 125
Sorbitol Acetal	127 - 129
Hypernucleator	128 - 132

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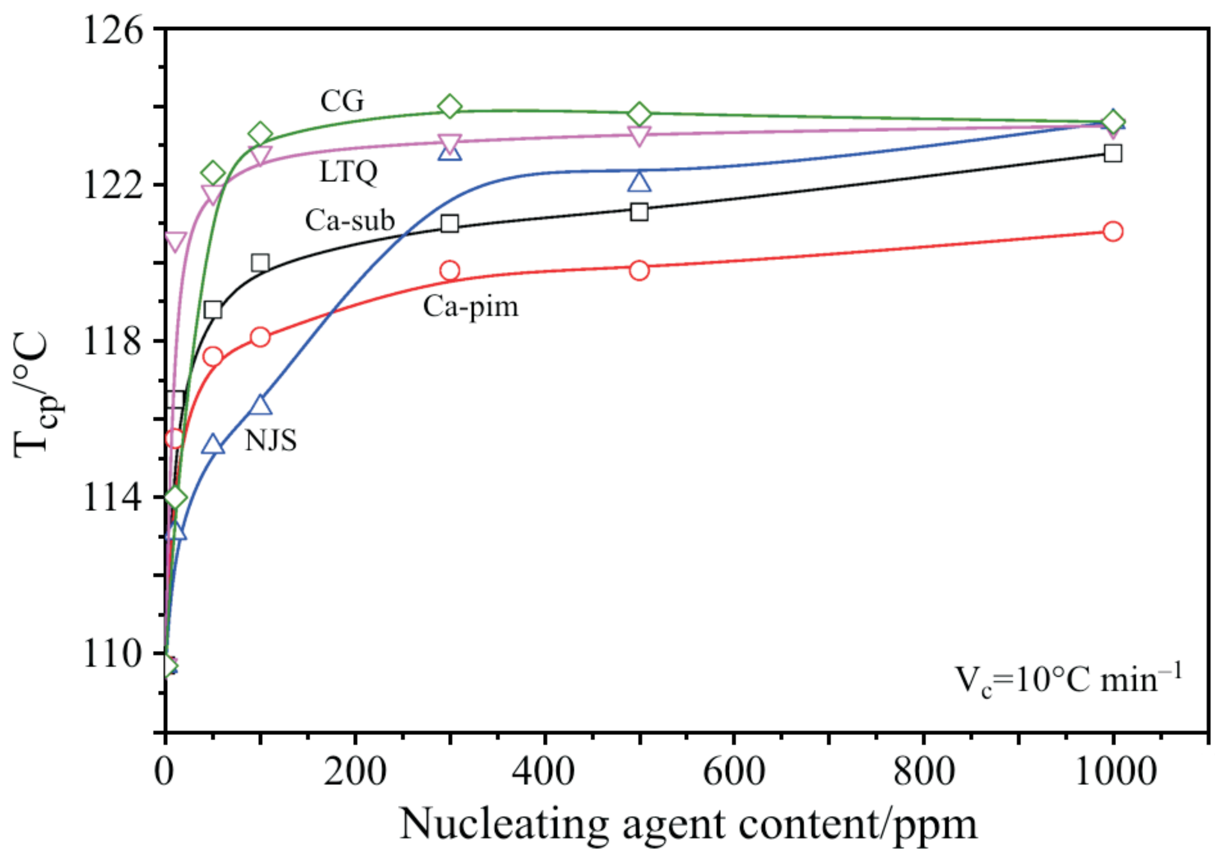
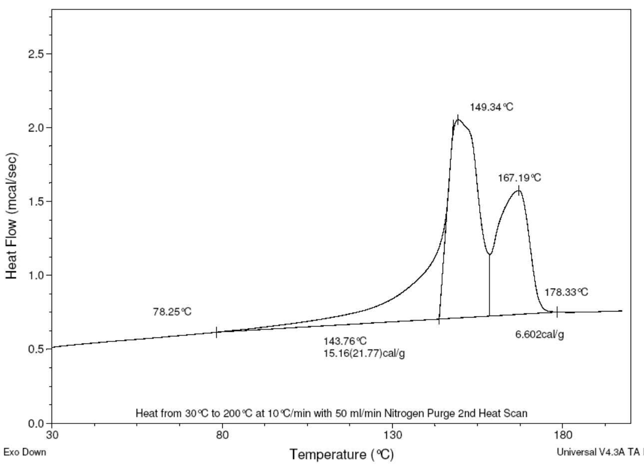
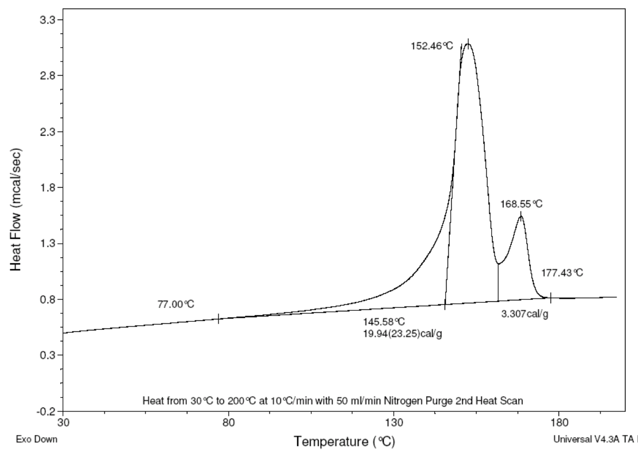
Effect of Beta Nucleant Concentration on Tc

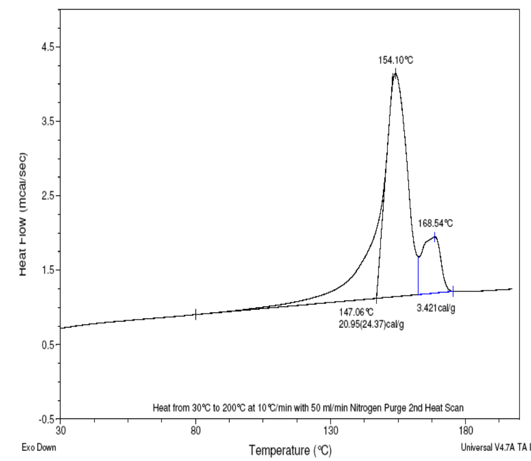


Tc vs concentration for various β-nucleating agents. LTQ = γ-quinacridone, Ca-sub - Calcium Suberate, Ca-pim = Calcium pimelate, NJS = New Japan NU-100, CG = experimental β-nucleant

2^{nd} Heat DSC Scans of Various Beta Masterbatches in Non-nucleated PP







MPM 1101 1^{st} gen.

Tc = 118.9 C

MPM 1112 2^{nd} gen.

Tc = 122.6 C

MPM 2000 3^{rd} gen.

Tc = 125.6 C

Tc Values for Alpha & Beta Nucleants