Development of High Thermal Insulation and Compressive Strength PP Foams Blown in Injection Molding with Mold Opening

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Outline

- Nano-Fibril Technology in Extrusion Foaming
  - Use of PTFE to develop nano-fibrils in the PP matrix
  - Effect of nano-fibrillated PTFE on the rheological behavior of PP
  - Effect of nano-fibrillated PTFE on the extrusion foaming behavior of PP

- Application of the Nano-Fibril Technology to Injection Molding
  - Effect of PTFE on the cellular structure of foam-injection-molded PP
  - Effect of cell structure on thermal conductivity of PP foam below 40 W/m-K
  - Effect of cell structure on mechanical properties of PP foam

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Nano-Fibril Technology in Extrusion Foaming

Development of PTFE as a foam enhancing additive

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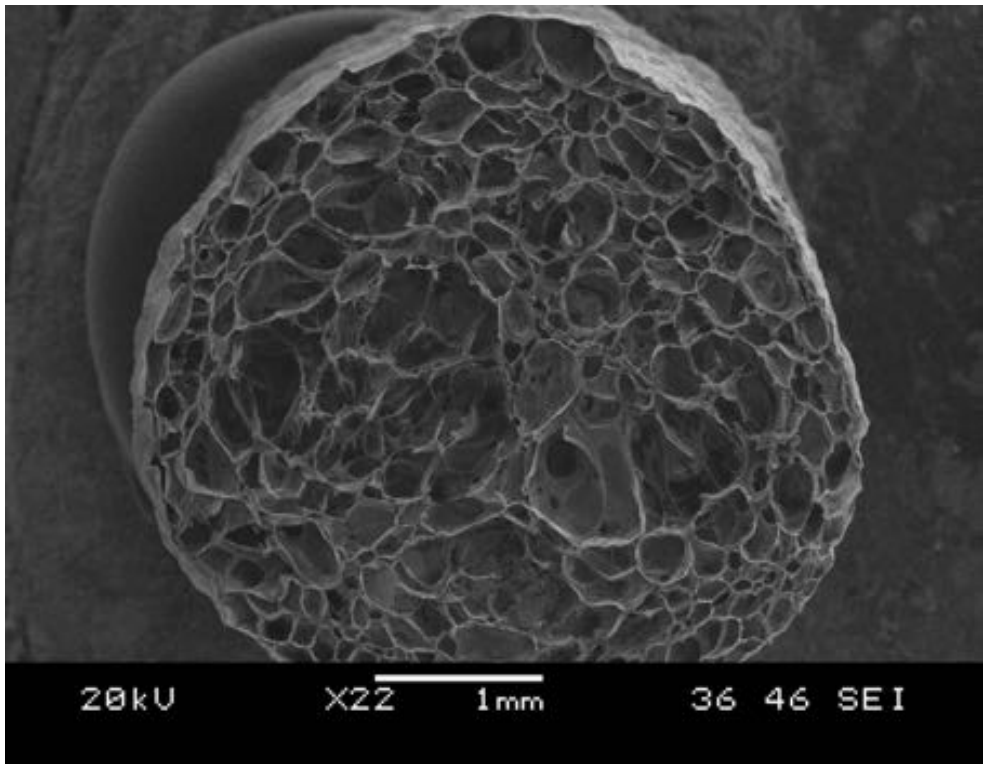
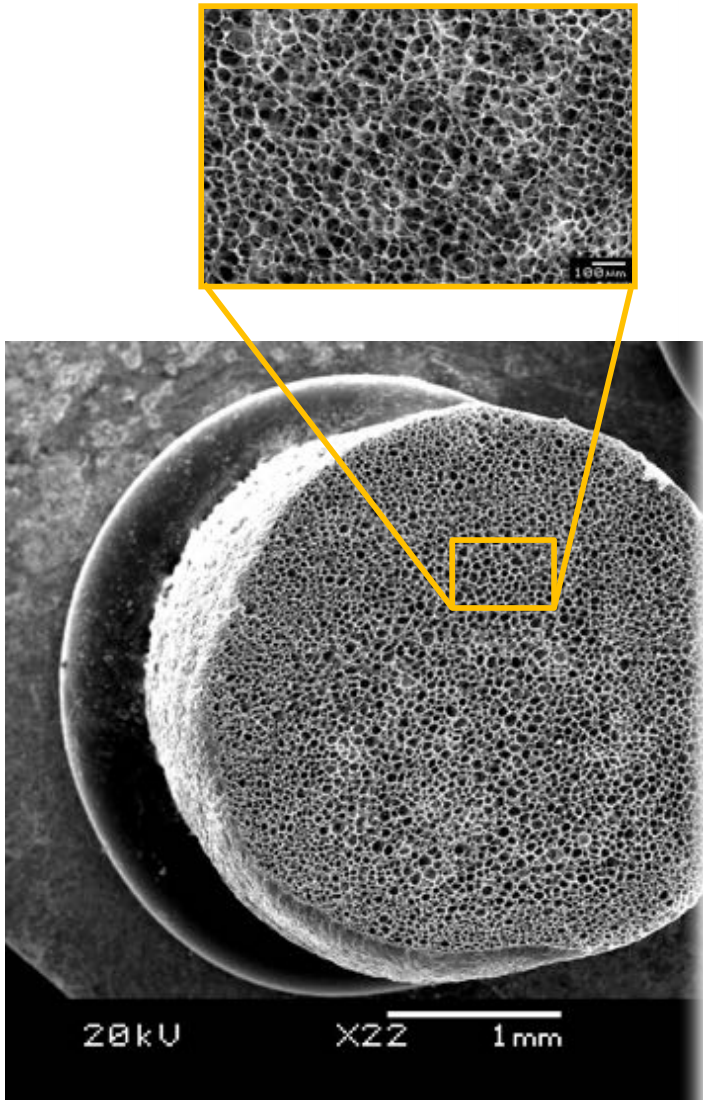
Linear PP



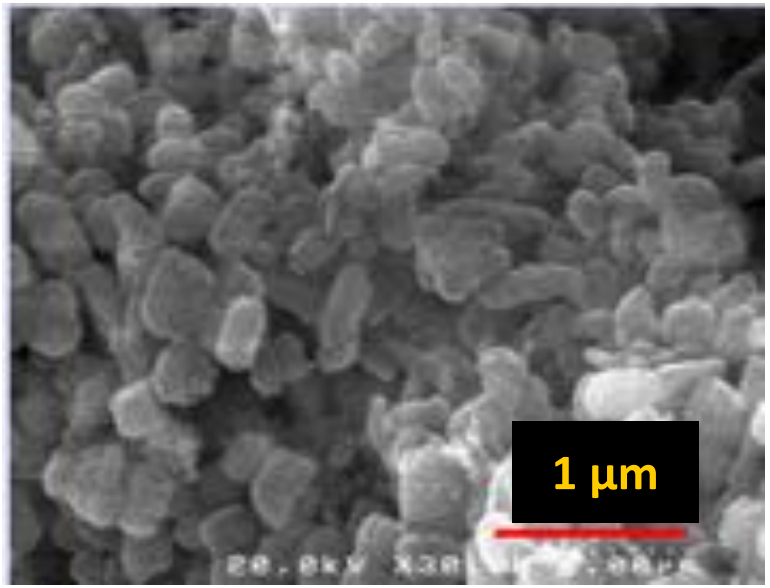
PTFE
3 wt%



A. Rizvi, C.B. Park, M. Yamaguchi, **JP2013-514463**, 2013, and **WO2013137301**, 2013
A. Rizvi, A. Tabatabaei, R. Barzegari, H. Mahmood, C.B. Park, *Polymer,* **2013**, 54, 4645-4652

Morphology of PTFE in linear PP

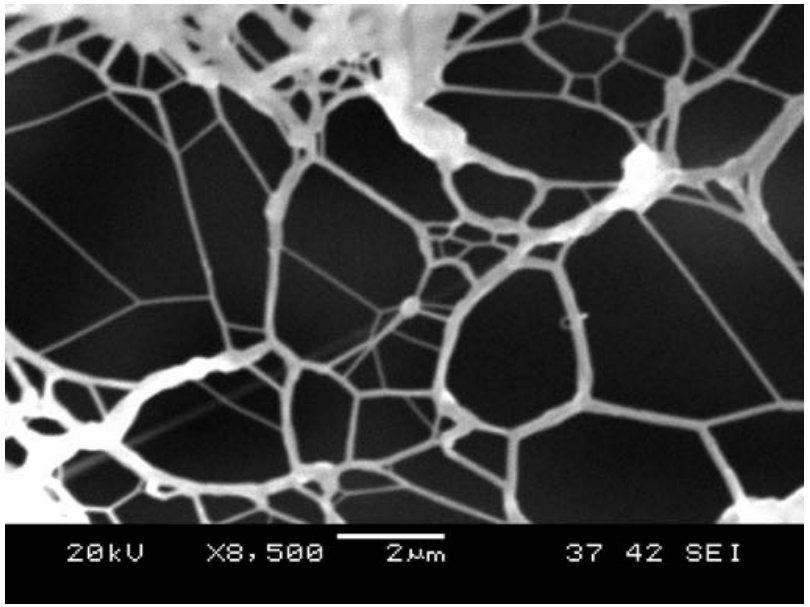
Original PTFE granules



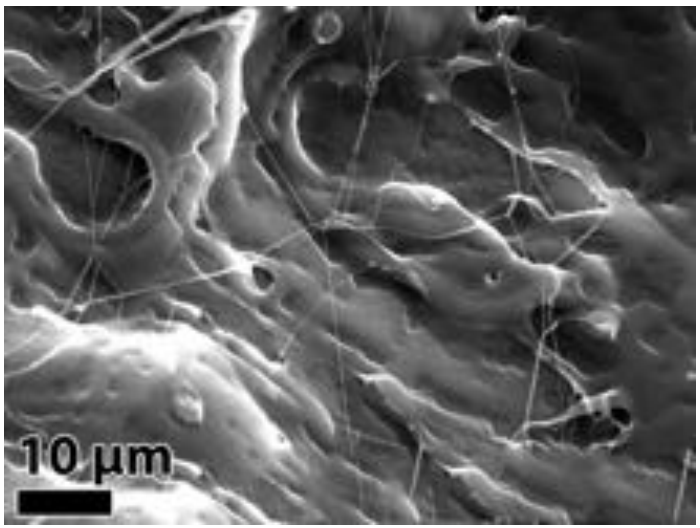
Spherical

Twin-screw extrusion of PTFE with PP

Residue of PP/PTFE (99.7/0.3 wt.%), after dissolving in xylene



Fibrillar structure



- PTFE readily undergoes **plastic deformation**
- PTFE exhibits high **ultimate strain**
- Entangled fibrils enhance **melt strength** of matrix

A. Rizvi, C.B. Park, M. Yamaguchi, JP2013-514463, 2013, & WO2013137301, 2013
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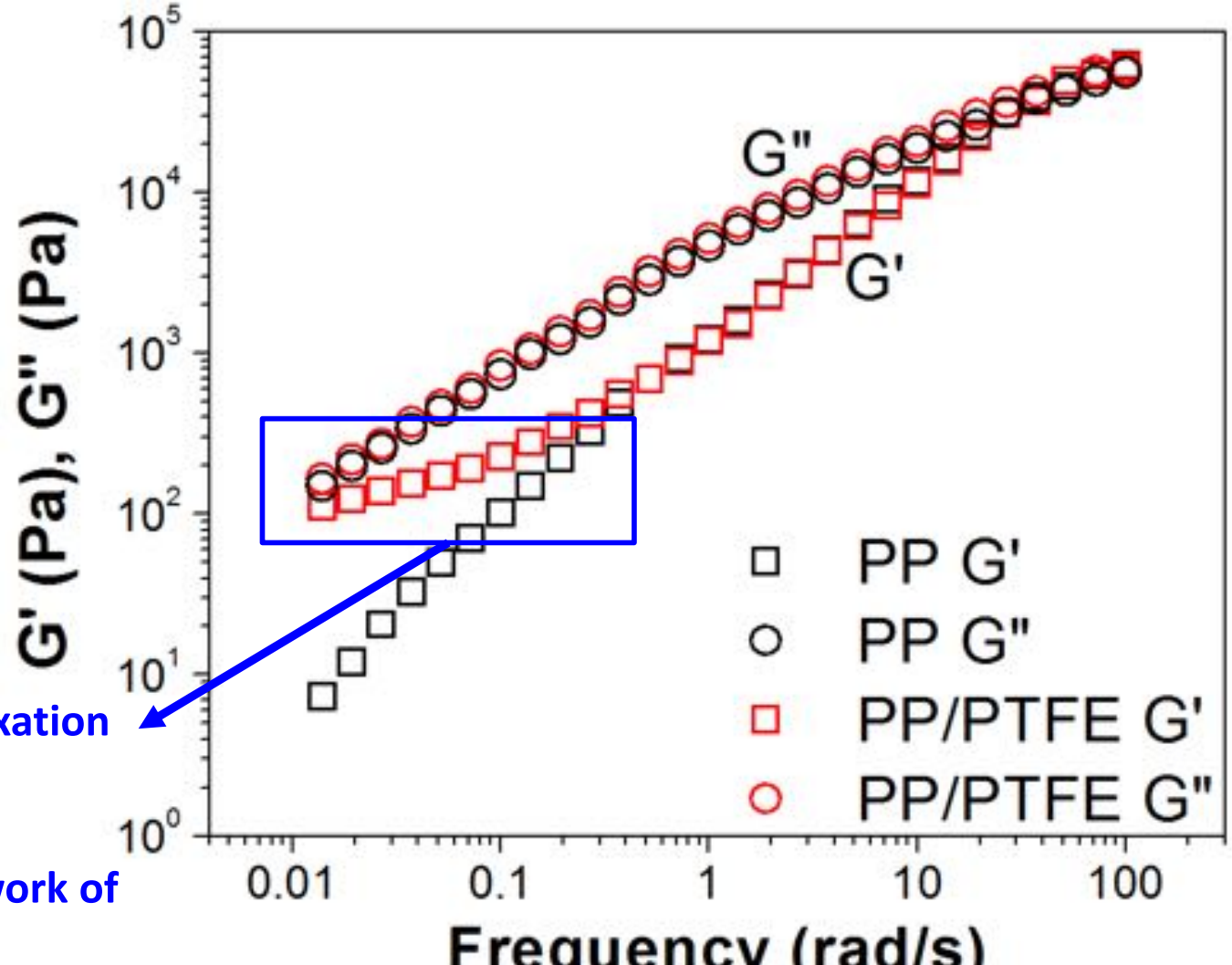
Frequency dependence of elastic and shear moduli at 190°C (PTFE 3 wt%)



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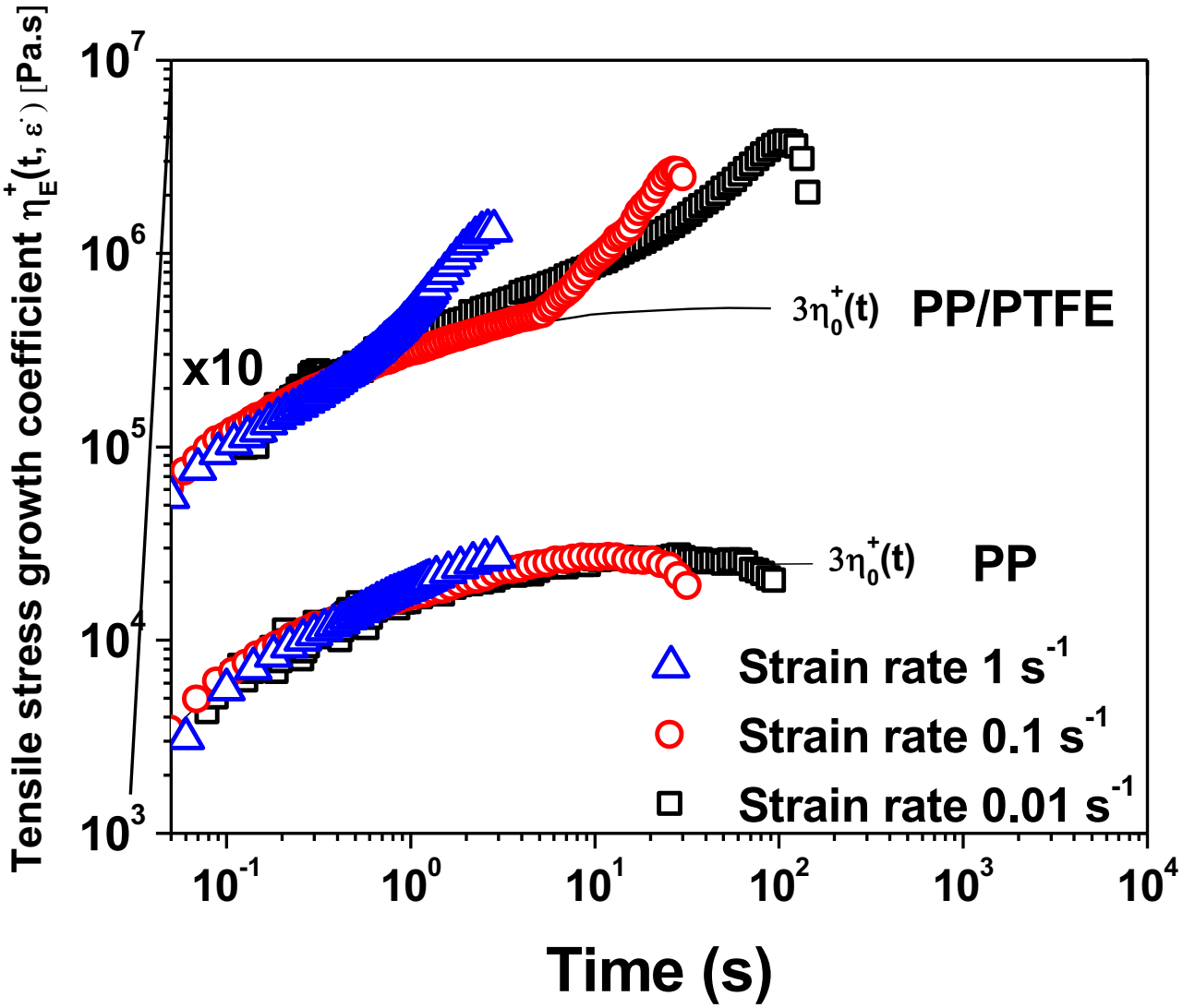
Strain-induced hardening in uniaxial elongational flow (PTFE 3 wt%)



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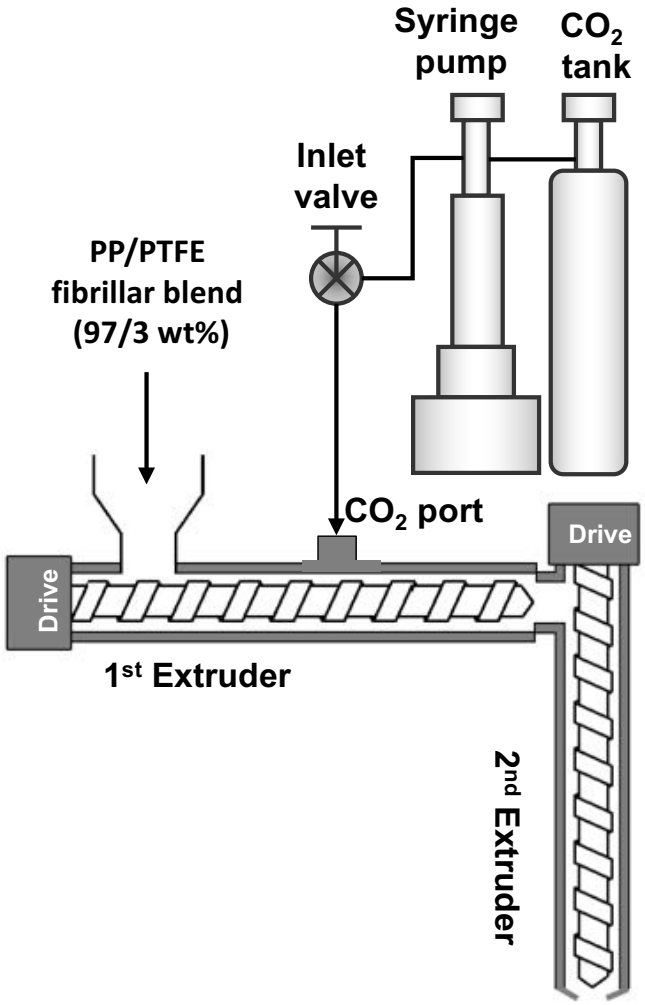
Experiment: Tandem foam extrusion system



Material	1. Linear PP 2. PP/PTFE (97/3 wt%)
Die	L/D ~8.3 (L = 10 mm / ø = 1.2 mm)
CO_2 Content	10 wt%
Equipment	Small tandem extruder (0.75”/ 1.5”)

SEM Images of extruded PP foams

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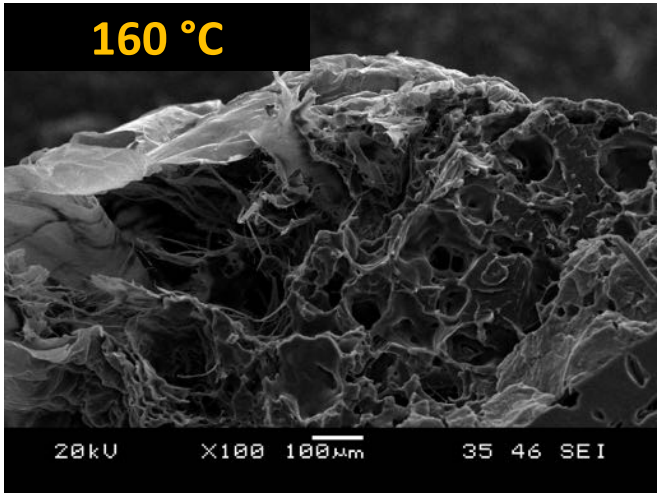
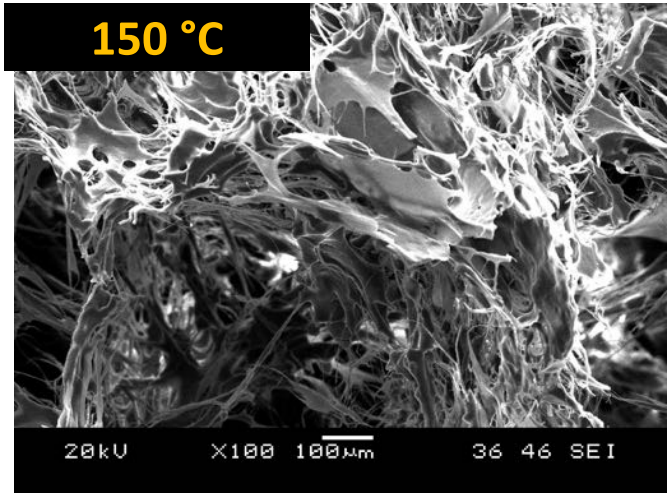
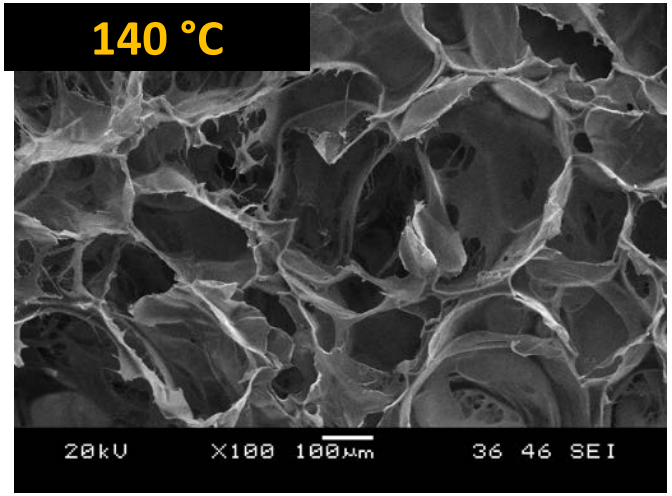
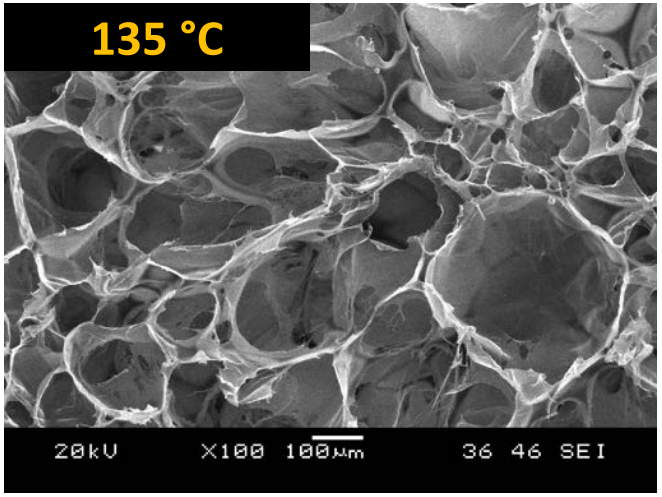
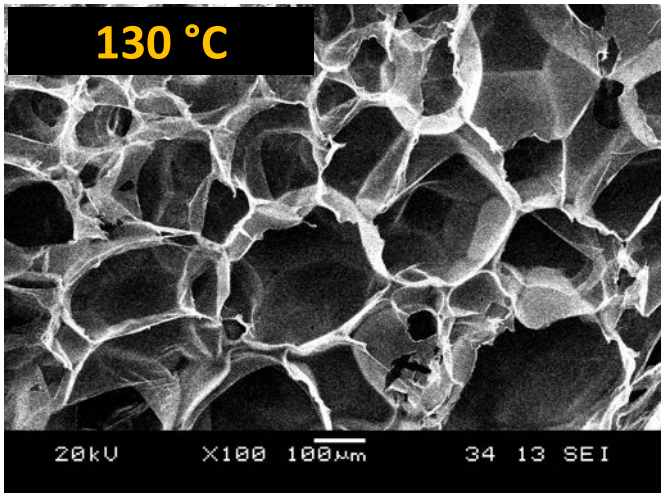


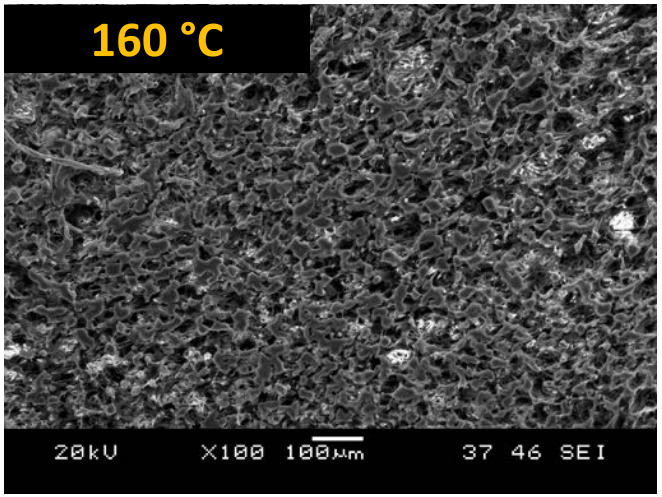


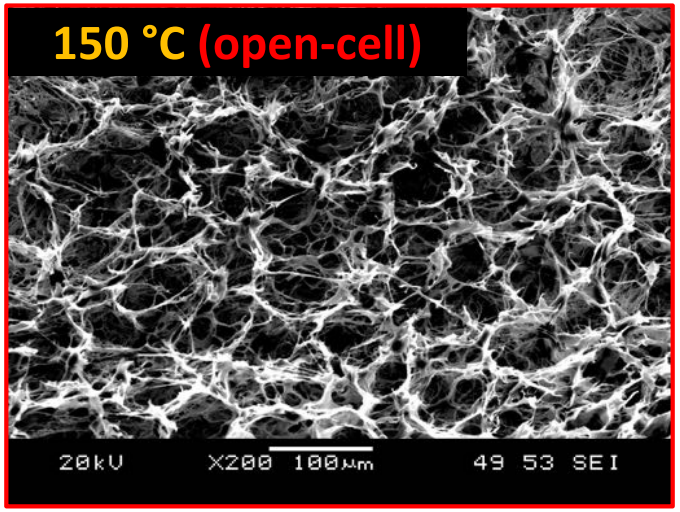


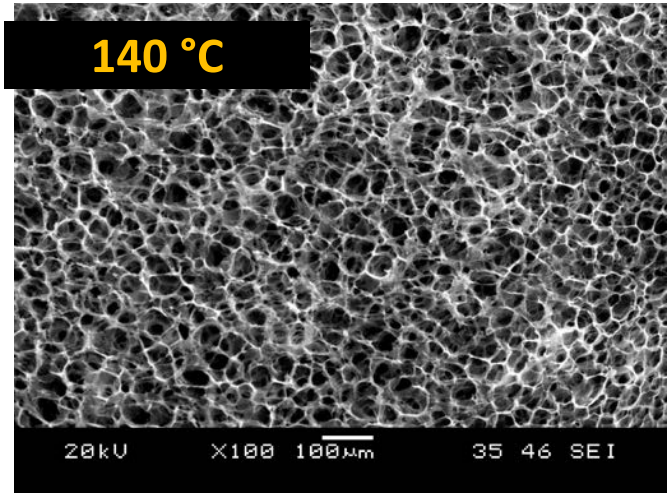


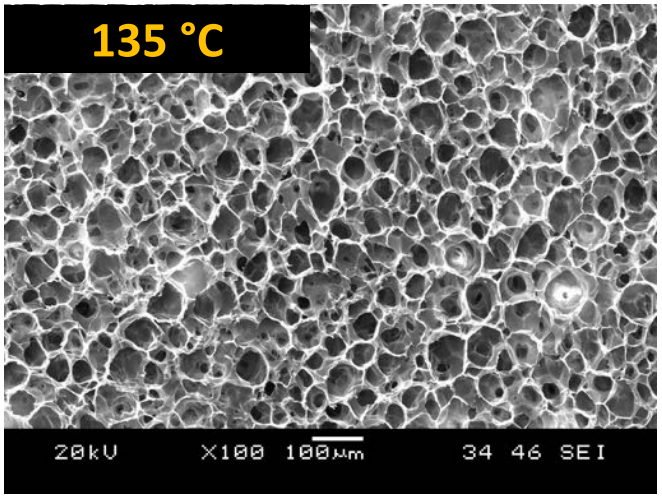


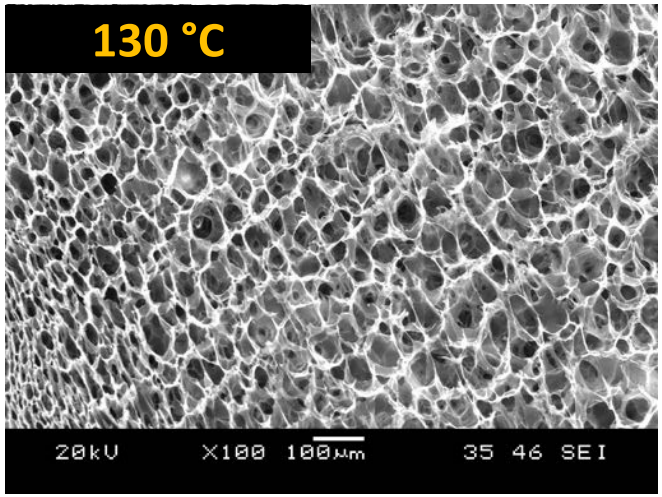
Die blockage occurred at 125°C

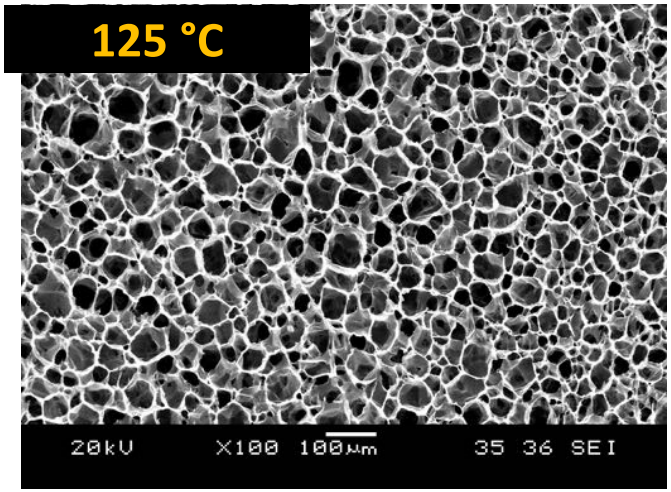


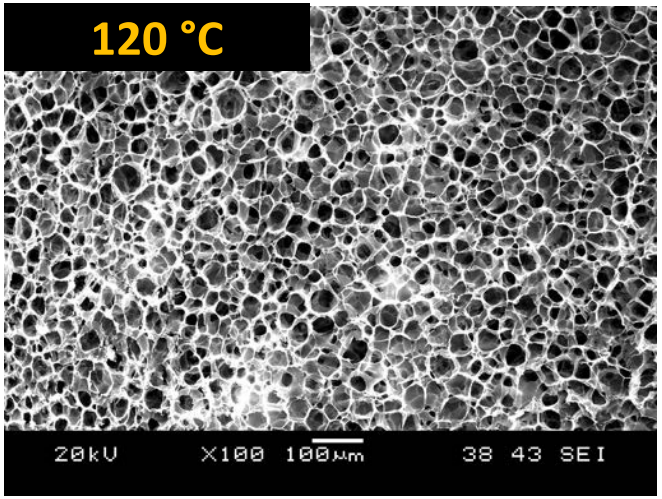






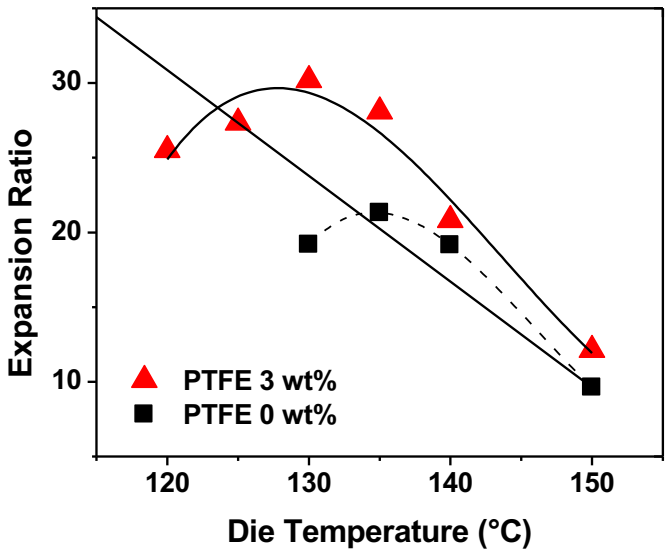


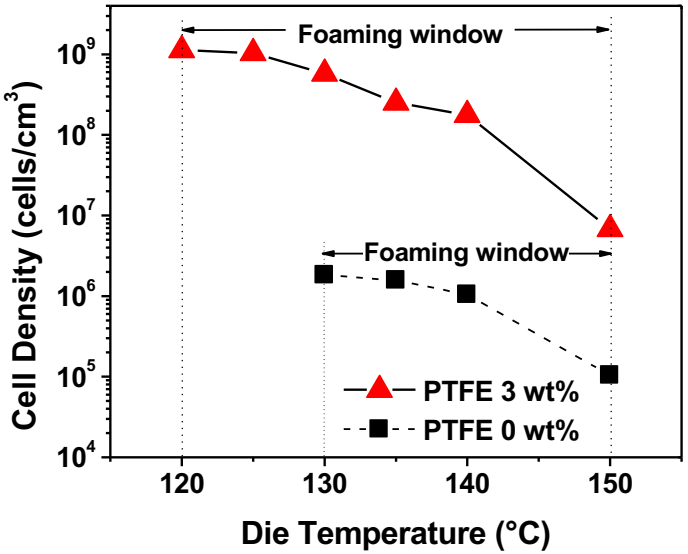


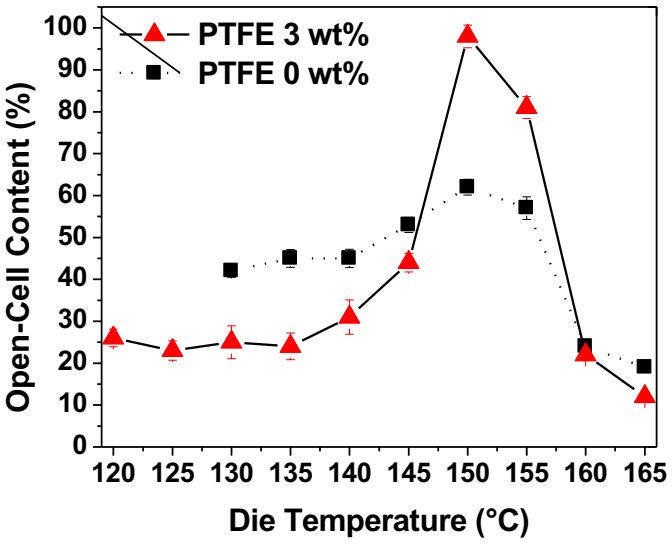


SEM Images of extruded PP/PTFE (97/3 wt%) foams

Foam characterization







- **Expansion Ratio:** Up to **10-fold** increase
- **Cell Density:** Up to **2 orders of magnitude** increase
- **Open-cell content**: Up to **97.7%** at 150°C

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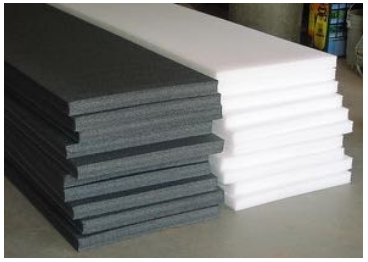
Application of the Nano-Fibril Technology to Injection Molding

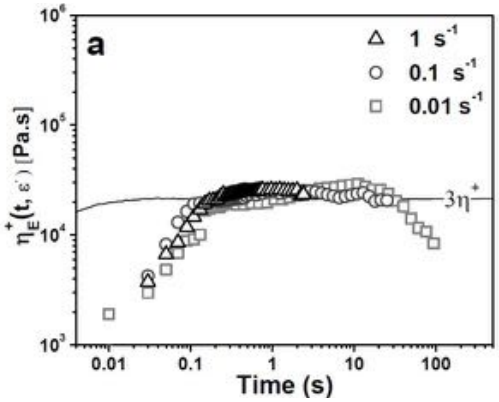
- Effect of PTFE on the cellular structure of foam-injection-molded PP
- Effect of cell structure on thermal conductivity of PP foam below 40 W/m-K
- Effect of cell structure on mechanical properties of PP foam

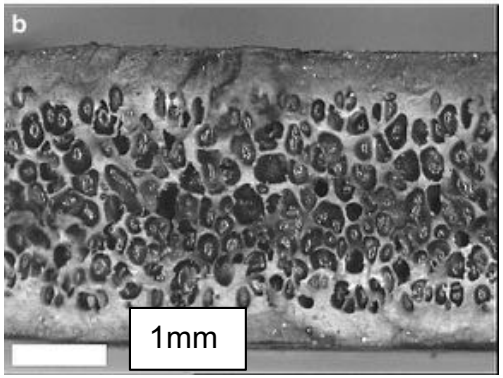
Introduction

- Advantage of PP foams
  - Low price
  - Low density
  - High stiffness
  - Good temperature stability
  - High chemical residence




- Difficulties to foam PP
  - Weak melt strength

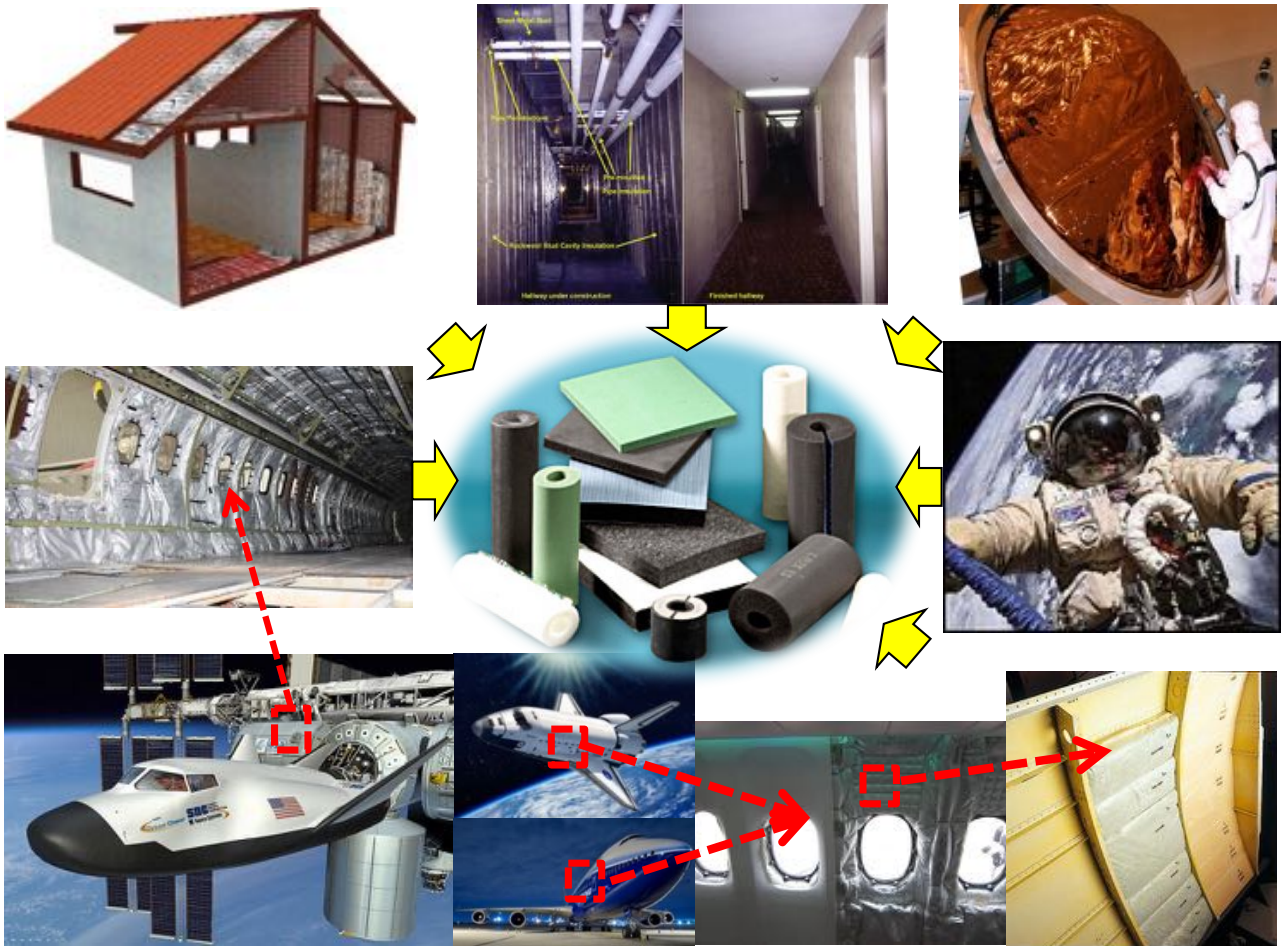




Apply PTFE to improve melt strength as well as crystallization, and to enhance strain hardening behavior in foam injection molding

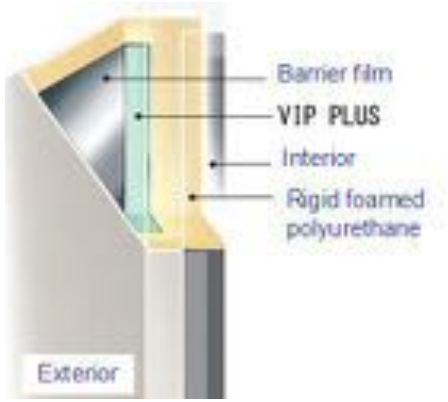
Introduction

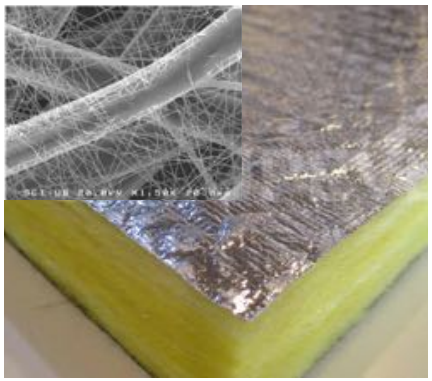
- The Requirements for Thermal Insulation Materials
  - Housing
    - Walls
    - Roofs
  - Space
    - Space suit
    - Spacecraft
    - Space station
    - Space probe
  - Airplane
  - Transport pipelines
  - Storage tanks

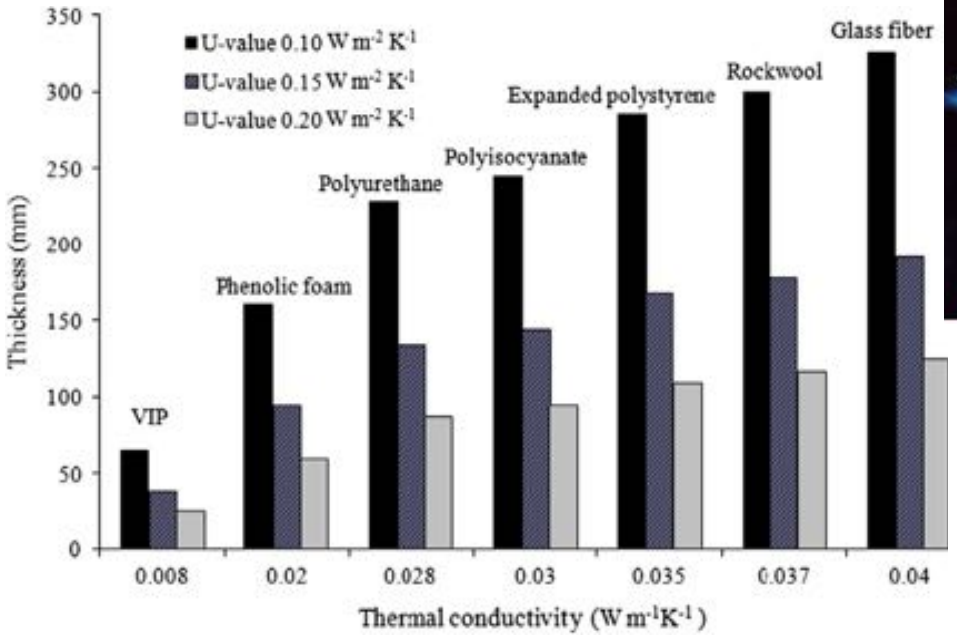


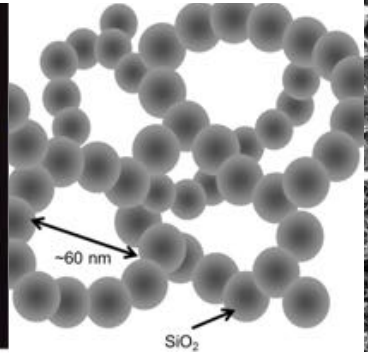
Introduction

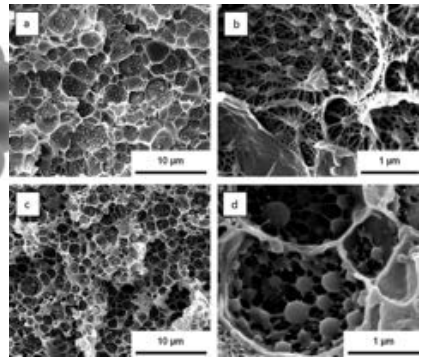
- Methods for thermal Insulation
  - vacuum insulation panels (VIPs)
  - Foams
  - Glass fiber
  - Aerogel materials







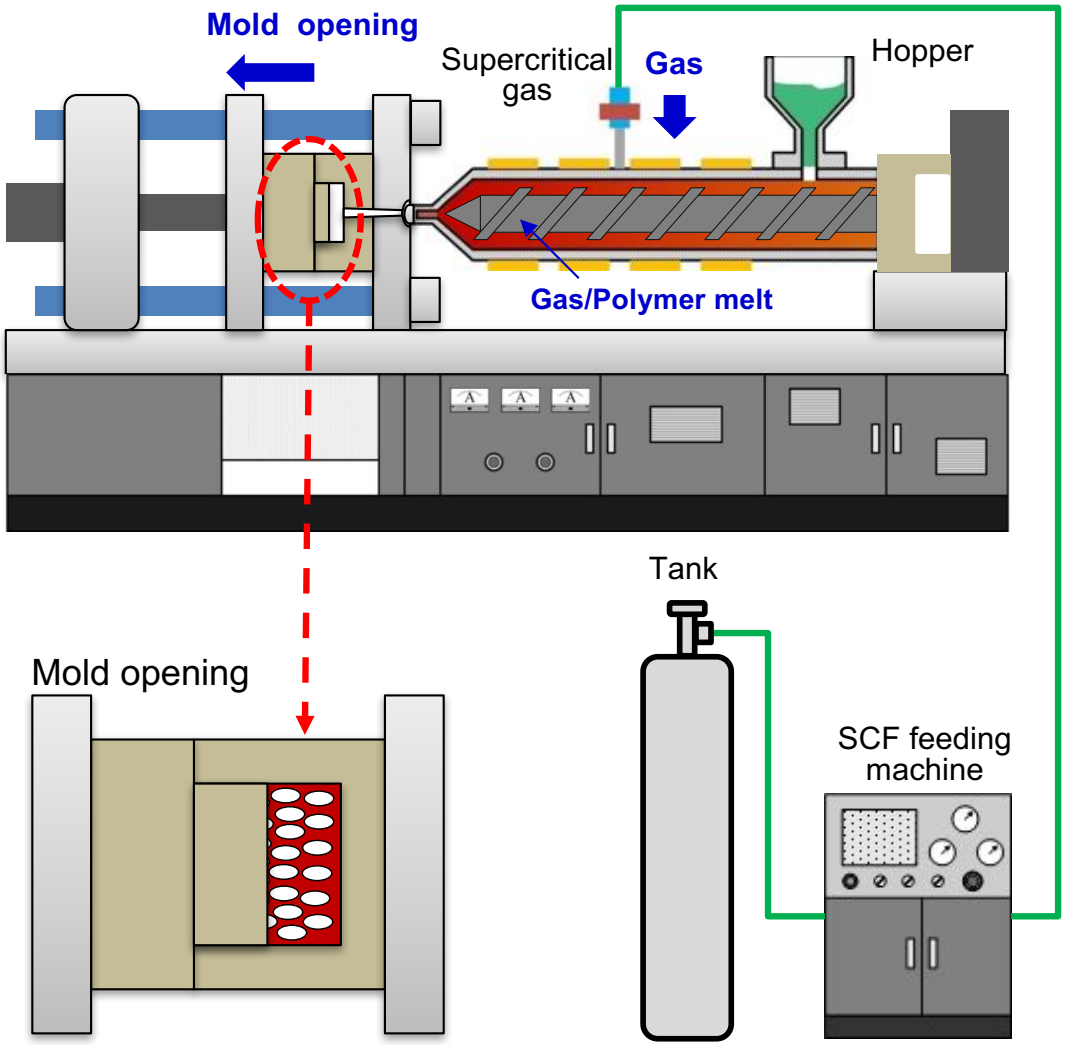




- Foams:
  - **Lower price**
  - Good processability
  - Highly efficient thermal insulation

Methodology

- High- P Foaming Approach
  - Close the mold
  - The screw is moving back
    - Metering the polymer
    - Dissolving supercritical CO_2
  - Inject the gas/polymer mixture
    - Completely filling the mold cavity
    - Packing with high pressure
  - Dwelling time
    - Allowing the material to cool
  - Mold opening to cause foaming
    - Nucleation and growth occurring



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Experimental

Materials

- Polypropylene
  - Homopolymer
  - Novatec FY4, supplied by Japan Polymer Corp.
    - MFR = 5 kg/10min (230℃，2.16kg)
- Polytetrafluoroethylene (PTFE)
  - METABLEN A-3000, Mitsubishi Rayon
- Blowing agent
  - 8 wt.% CO2, supplied by Linde Gas

Experimental

- Experimental equipment
  - 50-ton MuCell FIM equipment
    - Arburg Allrounder 270 [1]
    - Mucell SC feeding machine [2]

1

2

- Characterization and Rheology measurement
  - SEM JEOL JSM-6060 [3]
  - ARES-G2 Rheometer [4]
  - Hot Disk Thermal constant analyser [5]

3

4

5

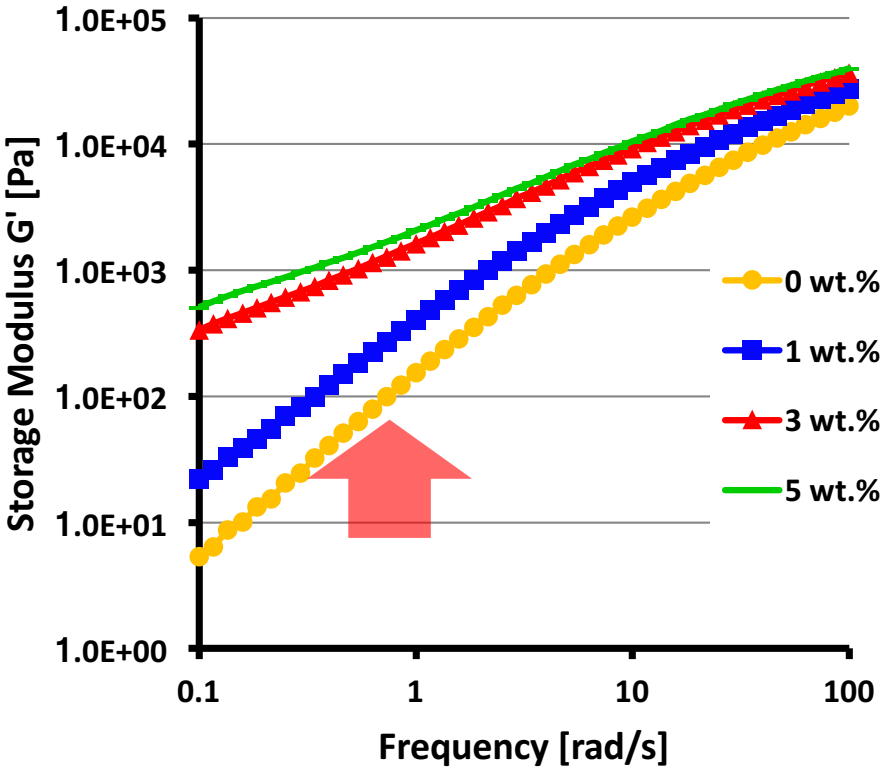
Experimental

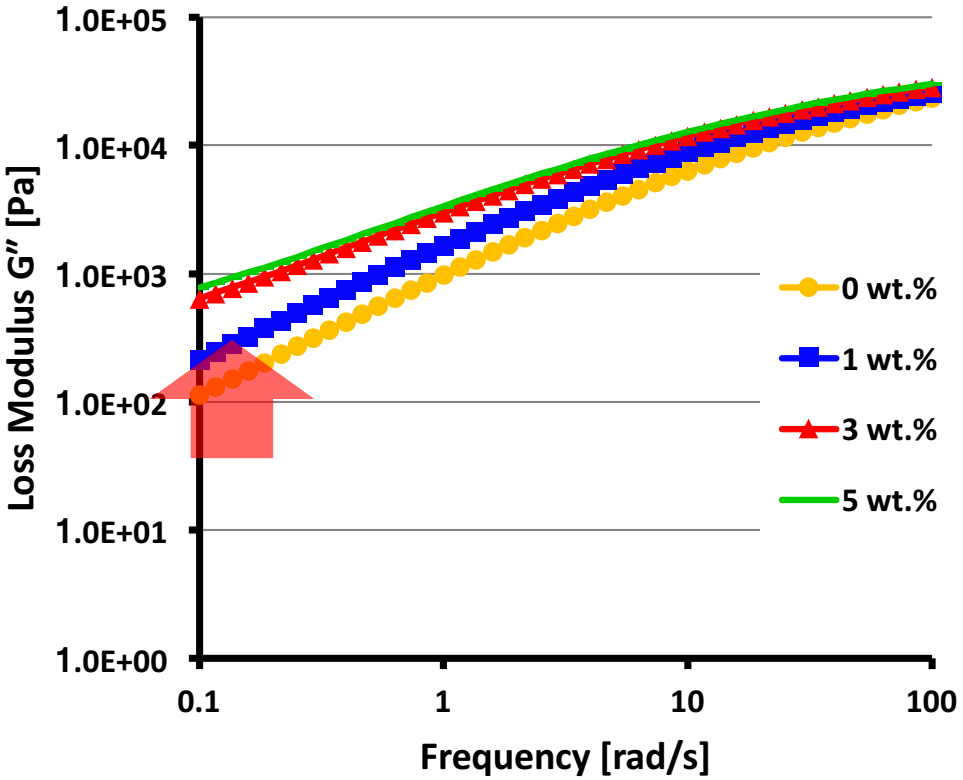
- Processing conditions for injection molding
  - A full factorial experiment was used and the processing conditions below were conducted for PP/PTFE (0%wt, 1%wt, 3%wt, 5%wt)

Parameters	Values
CO_2 content (%)	8.0
Melt temperature (^oC)	230
Mold temperature (^oC)	80
Injection speed (cm^3/s)	100
Dwelling time (s)	30, 32.5, 35, 37.5, 40, 42.5
Shot size (cm^3)	60
Packing pressure (MPa)	30
Mold opening distance (mm)	12, 15, 18, 21, 24

Results and discussion

- Rheological Properties of PP/PTFE blend: Effects of PTFE on Rheological Property

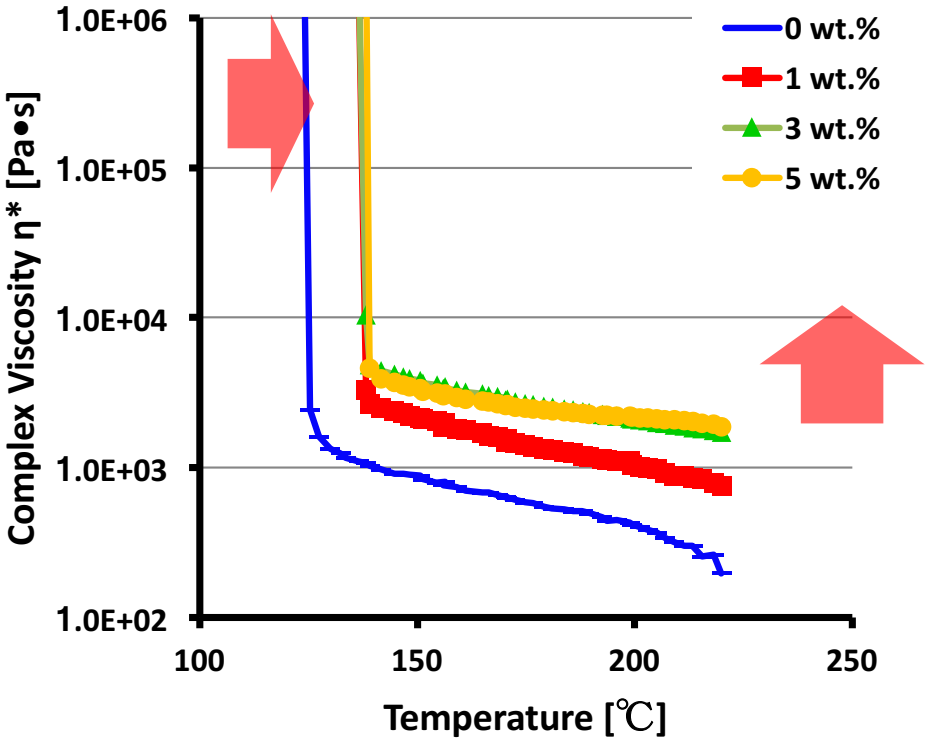


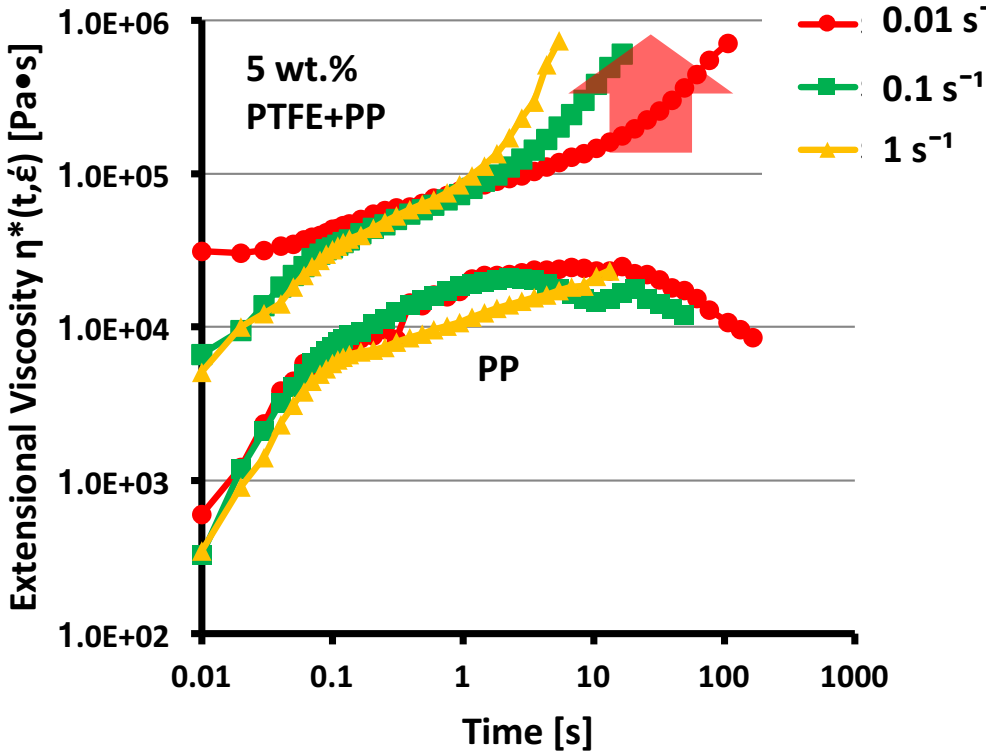


- In the low shear rate region, G' and G" increased, as the PTFE content increased.
- Indication of a network structure formed

Results and discussion

- Rheological Properties of PP/PTFE blend: Effects of PTFE on Rheological Property



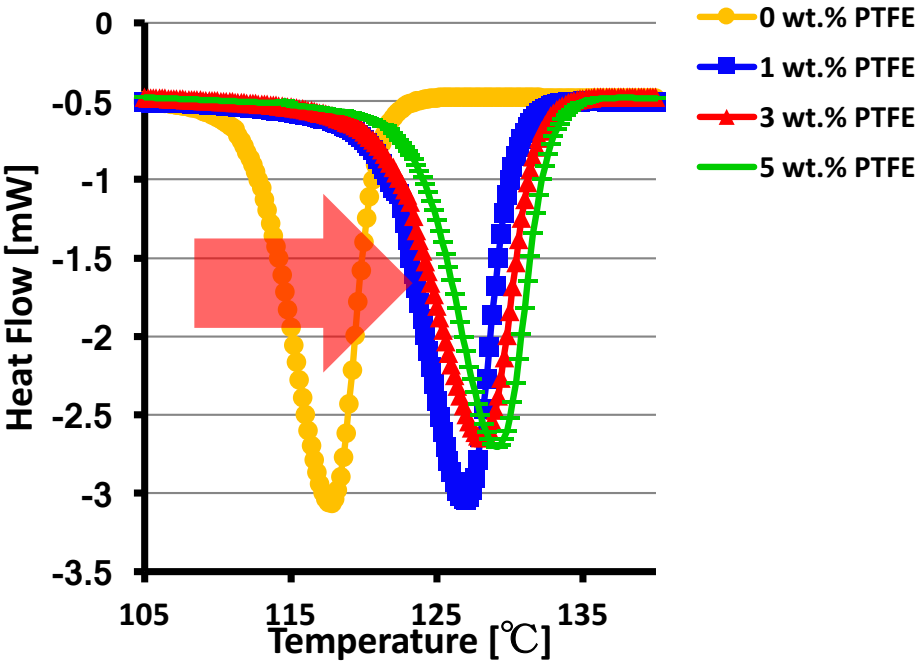


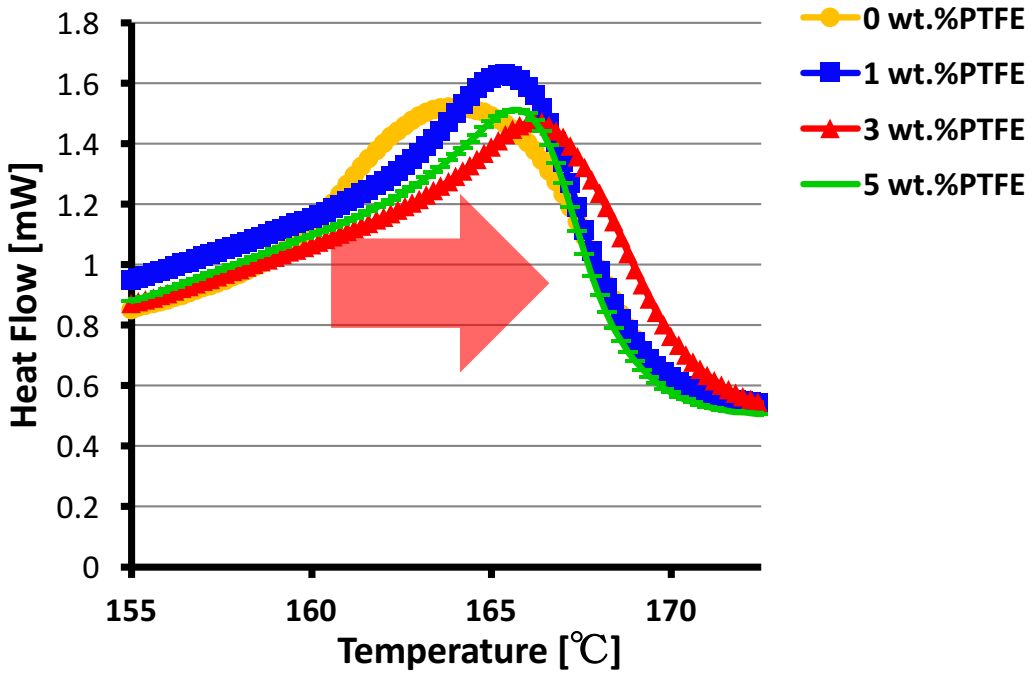
- The crystallization temperature and the viscosity increased with an increased PTFE content.
- PTFE dramatically enhanced the strain hardening behavior.

Results and discussion

- Thermal Properties of PP/PTFE blend: Effects of PTFE on Crystallization

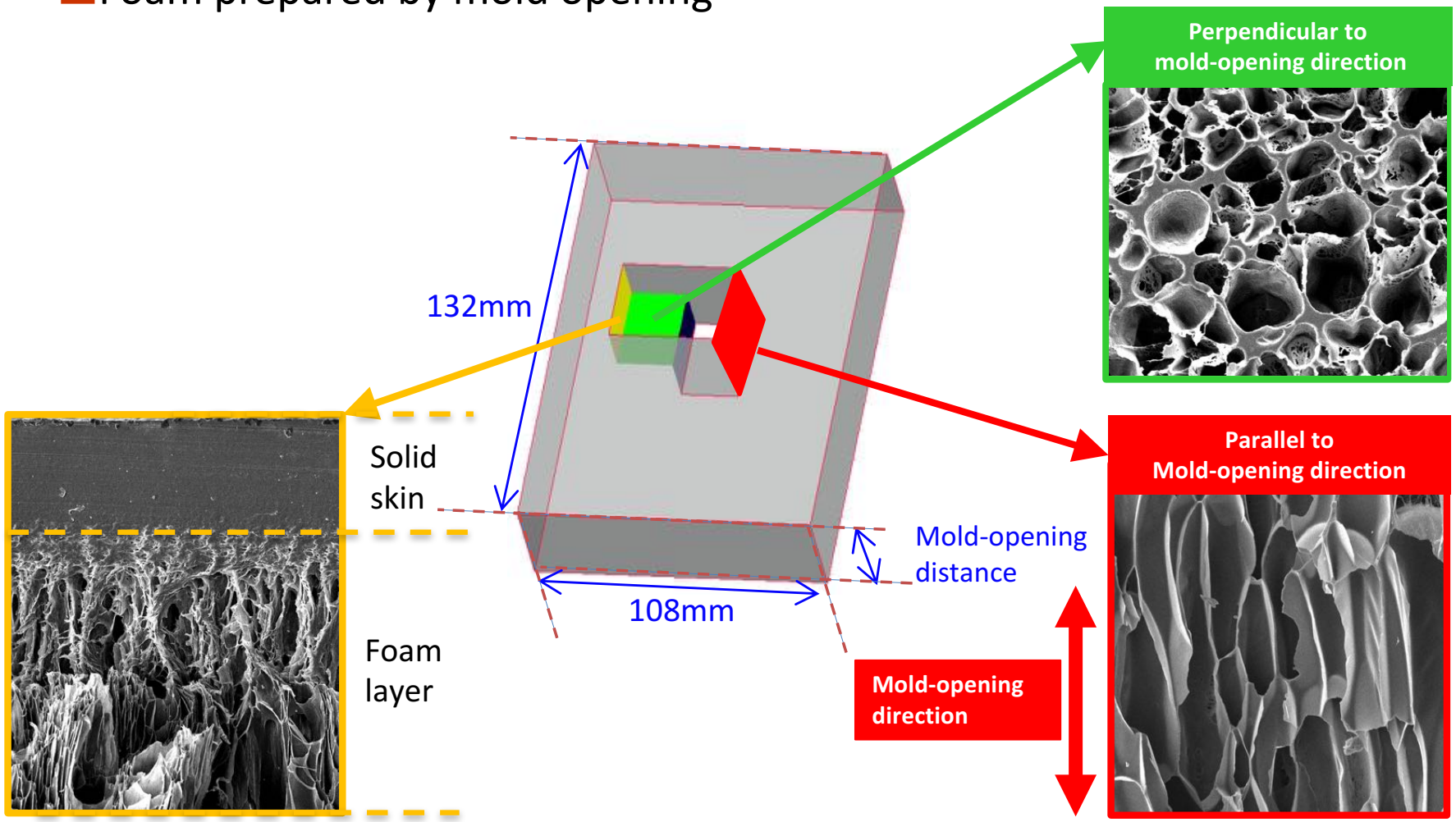
	crystallization peak	enthalpy-heating	melt temperature	degree of crystallinity
PP-FY4	117.82	74.82	163.79	0.3614
PP+1PTFE	126.94	81.61	165.36	0.3982
PP+3PTFE	128.19	80.68	166.13	0.4018
PP+5PTFE	128.89	75.38	165.77	0.3833





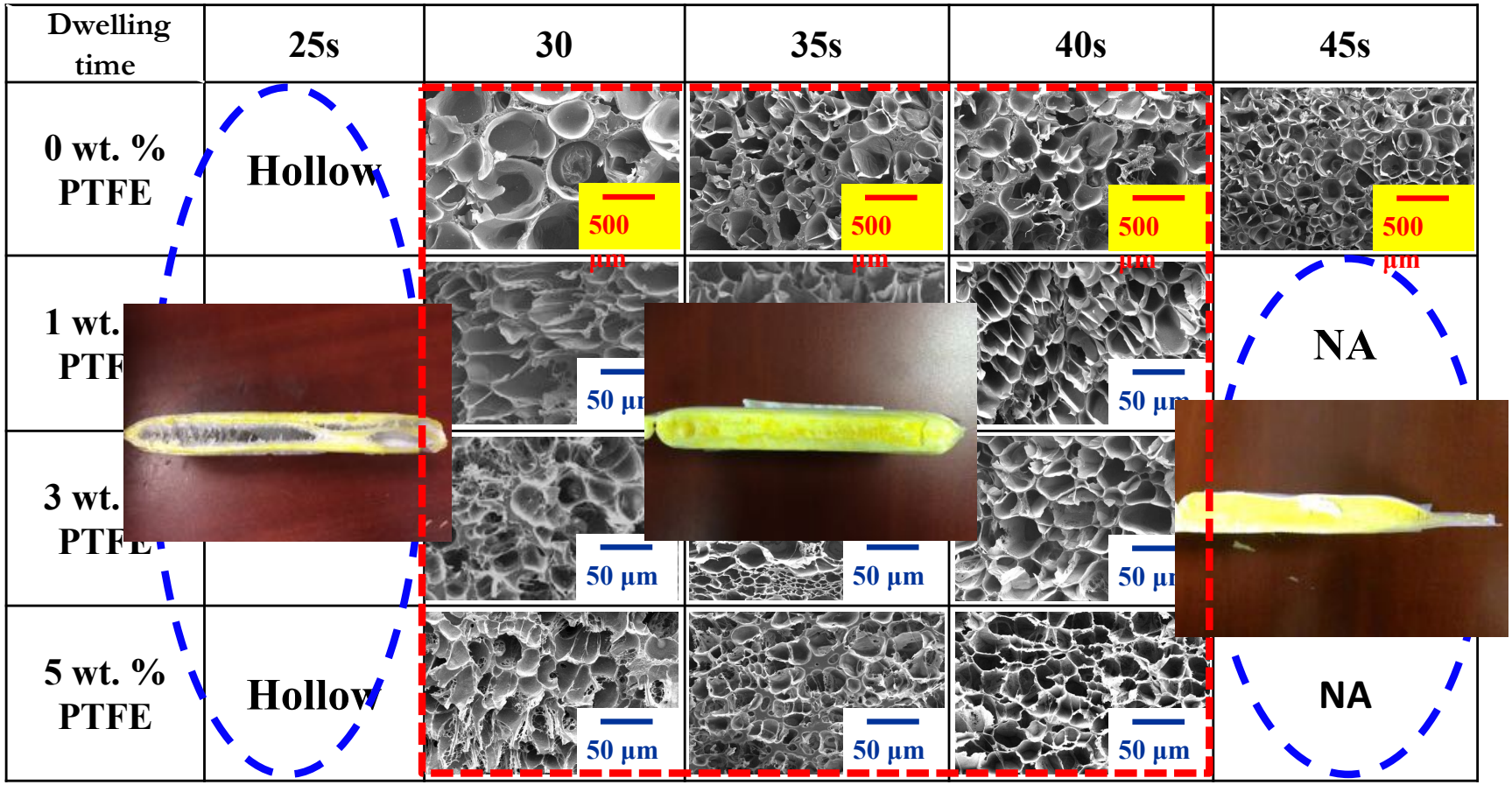
Results and discussion

- Cell structure of foam with PTFE
  - Foam prepared by mold opening



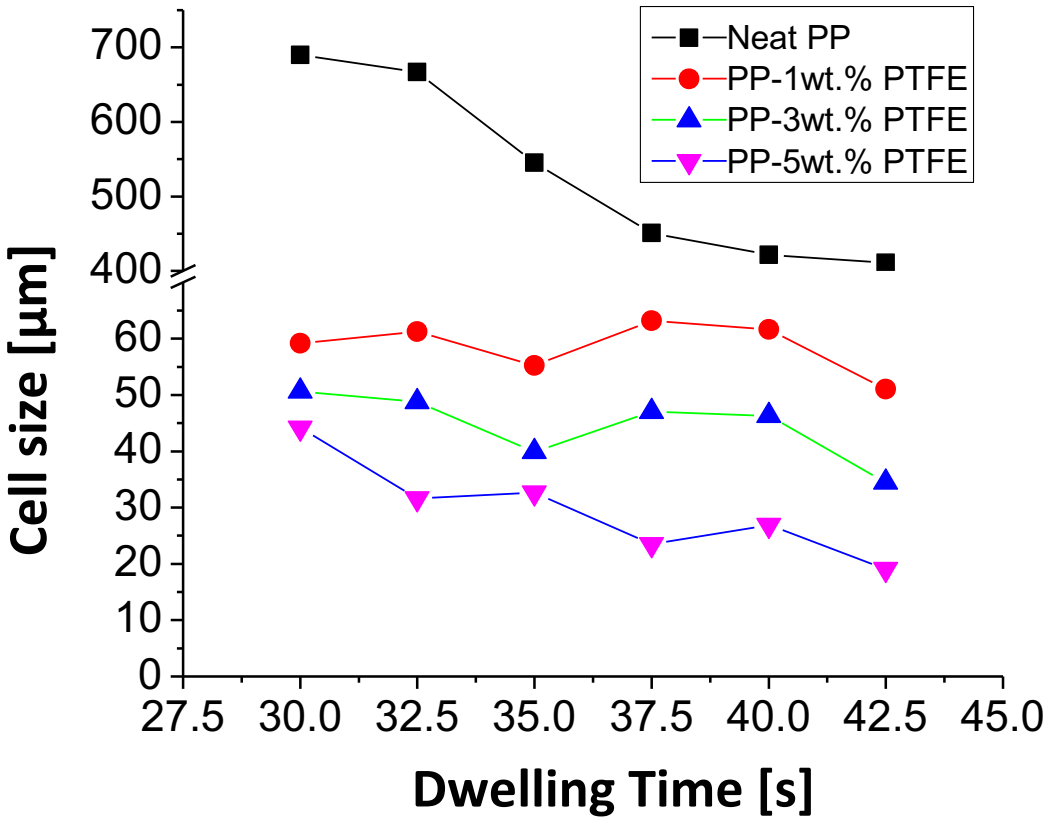
Results and discussion

- Cell structure of foam with PTFE
  - SEM Images (perpend. to Mold-opening) of Foam (Expansion ratio 7.5)



Results and discussion

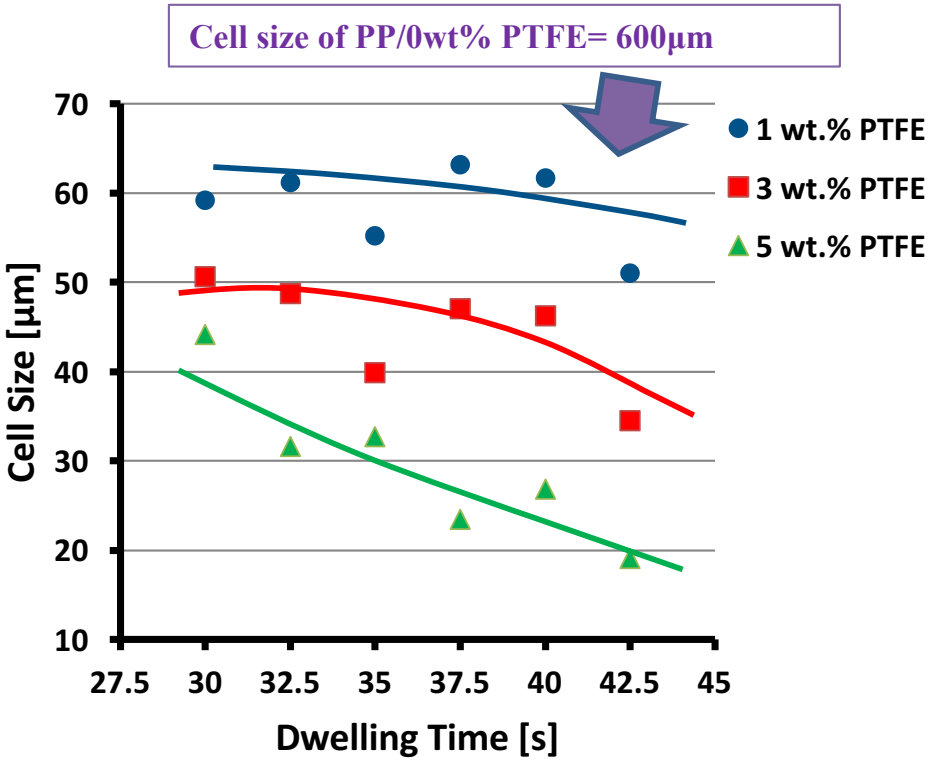
- Cell structure of foam with PTFE
  - Effect of dwelling time on cell morphology (perpend. to Mold-opening)

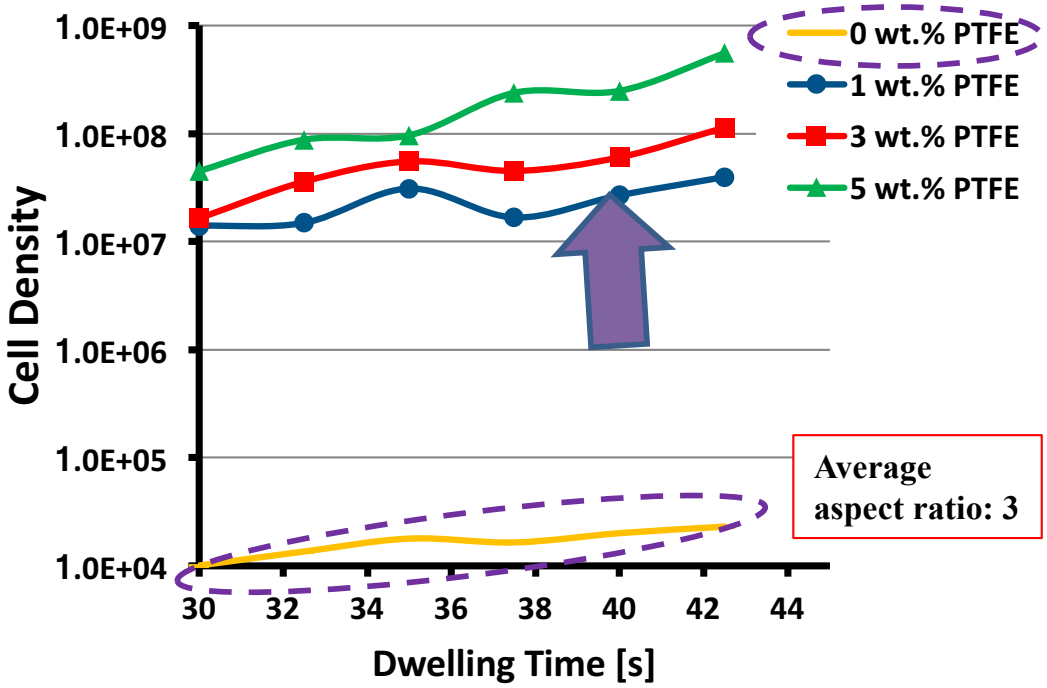


Volume Expansion Ratio: 7±1

Results and discussion

- Cell structure of foam with PTFE
  - Effect of dwelling time on cell morphology (perpendicular to mold-opening),

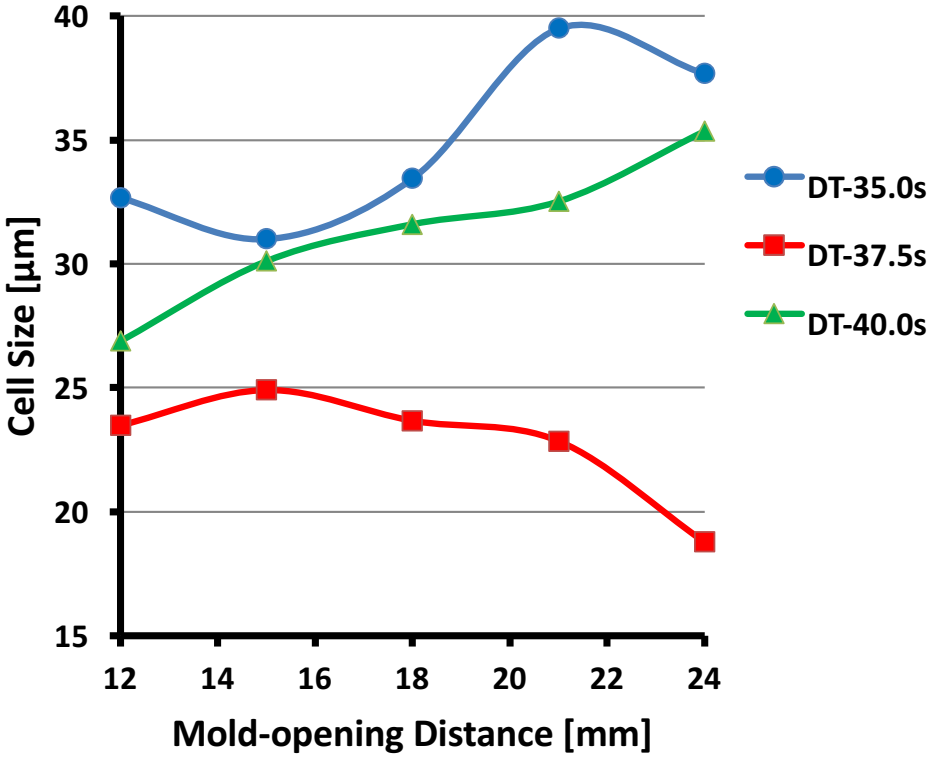


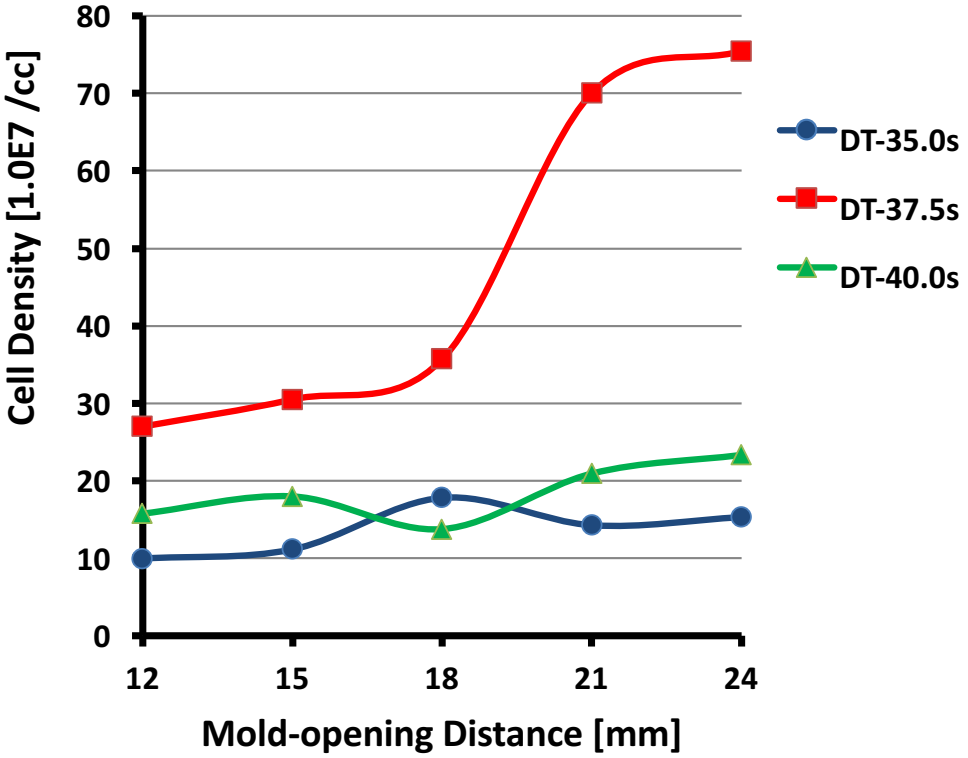


- PTFE improved the cell morphology significantly
  - Cell density: 3-orders of magnitude increased
  - Cell size: 1-order of magnitude decreased (~600µm → 50µm)

Results and discussion

- Cell structure of foam with PTFE
  - Effect of Mold-opening distance (expansion ratio) on cell morphology

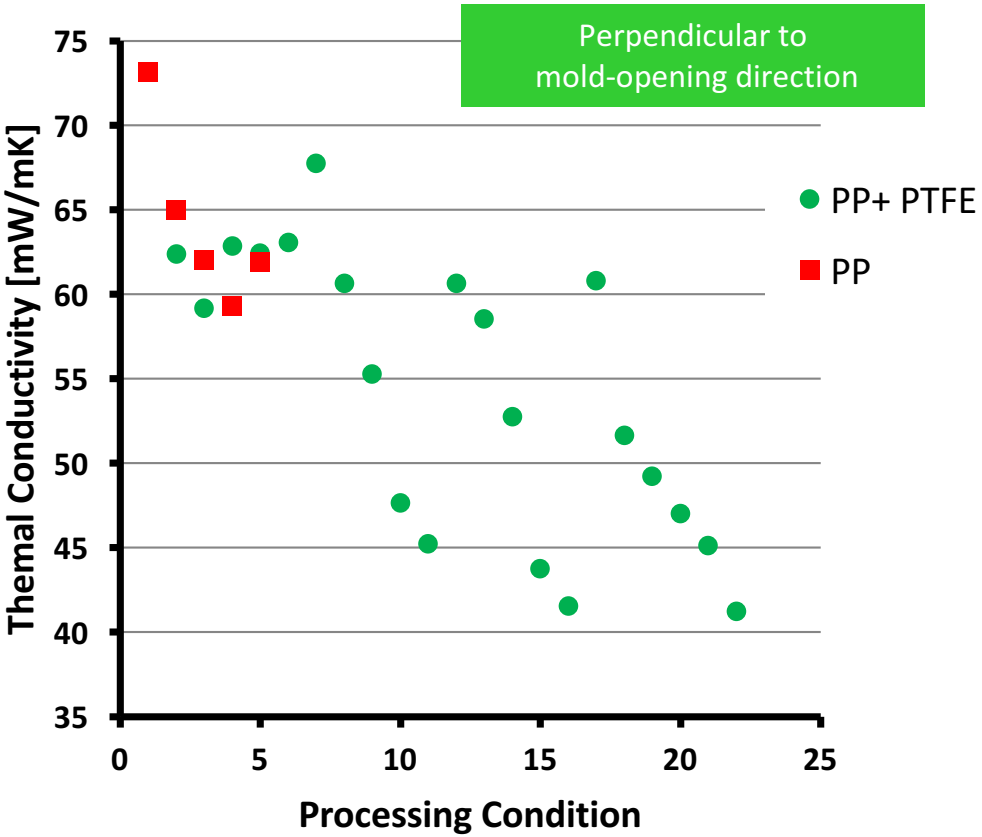


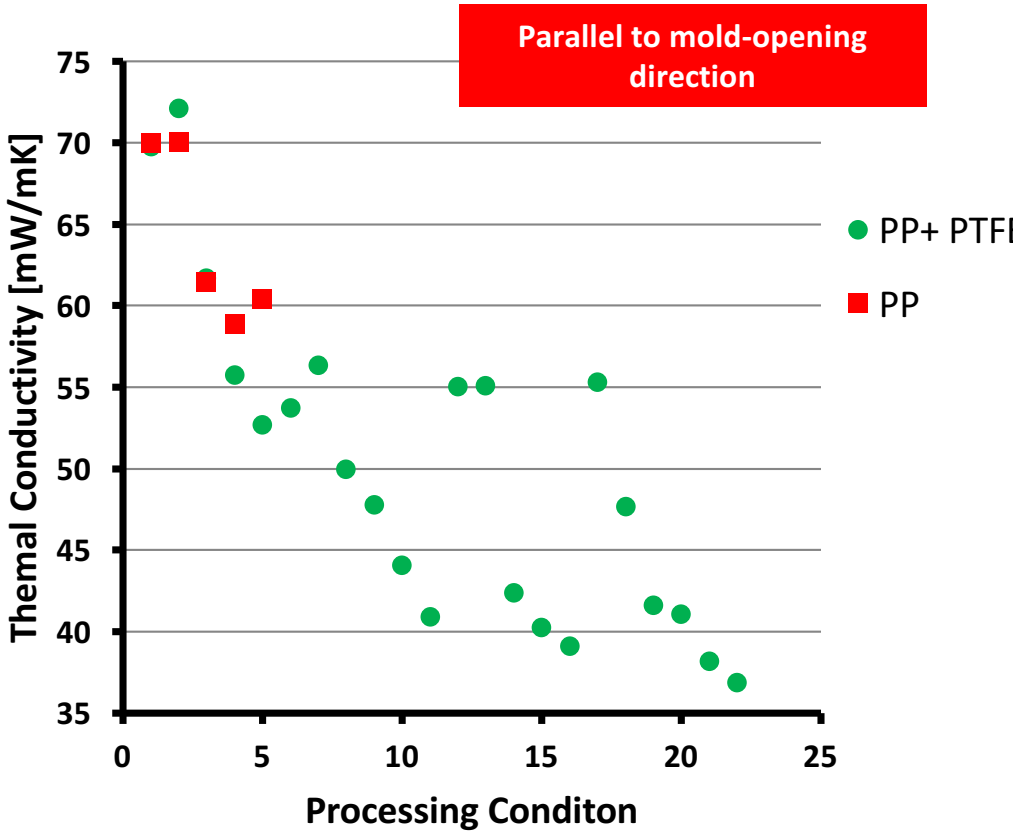


- There was little effect of the mold-opening distance on the cell size and cell density of PP/PTFE foams

Results and discussion

- Thermal insulation properties
  - Effect of PTFE on thermal conductivity

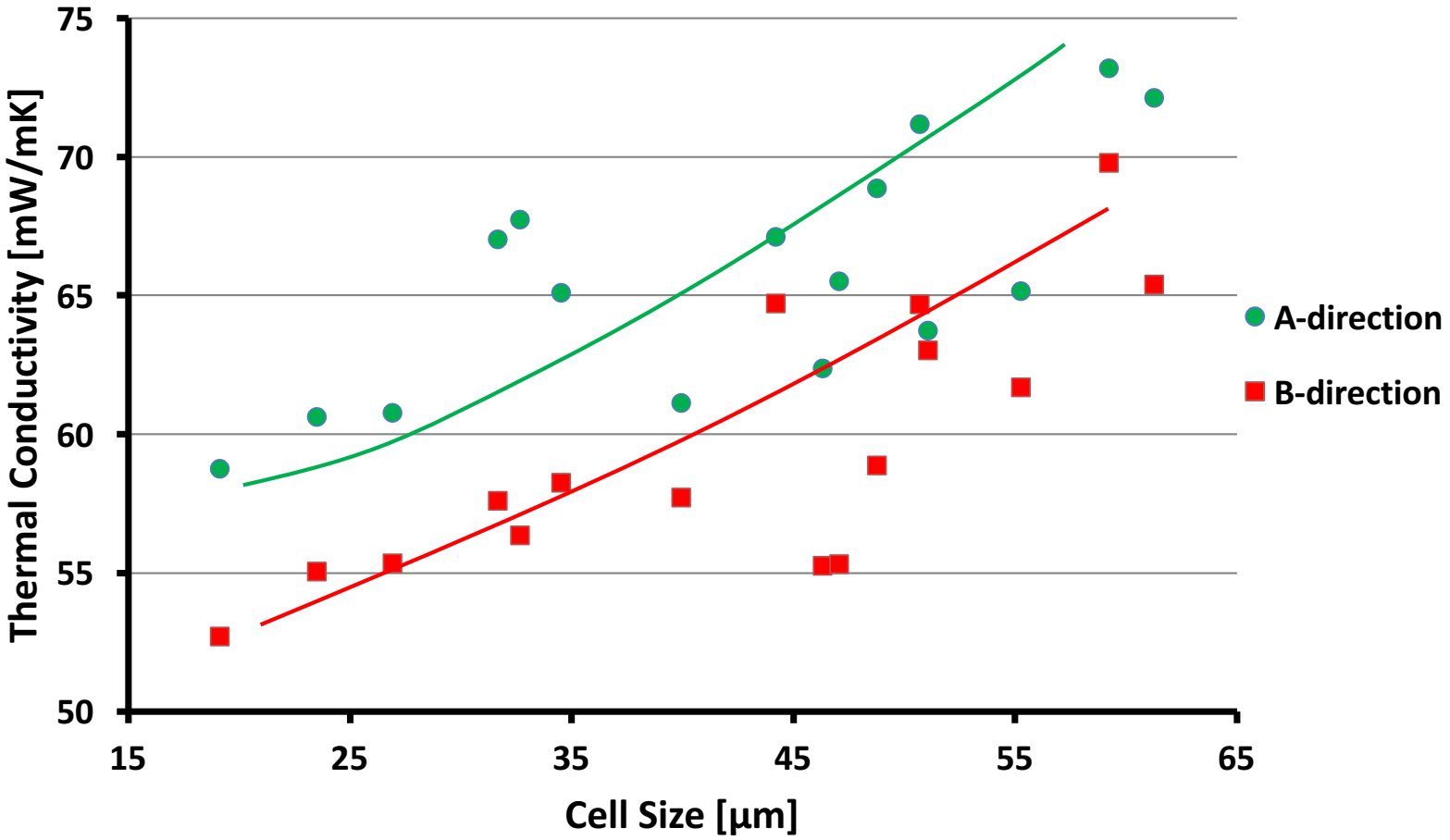




- PTFE enhanced the thermal insulation significantly!

Results and discussion

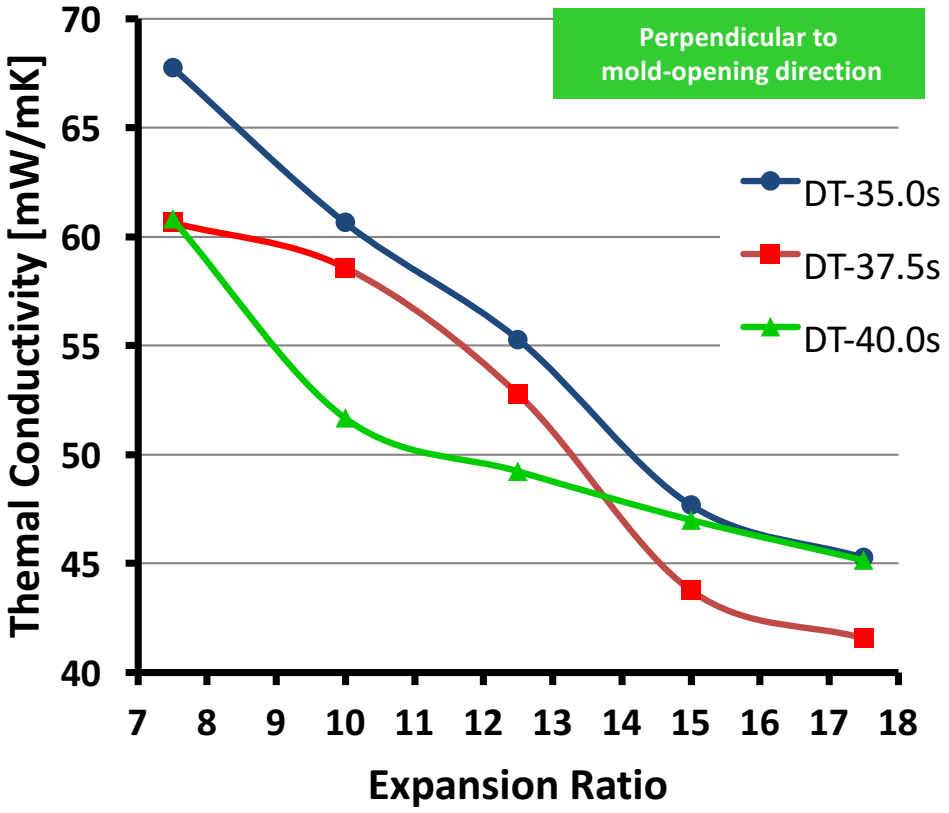
- Thermal insulation properties
  - Effect of cell size on thermal conductivity

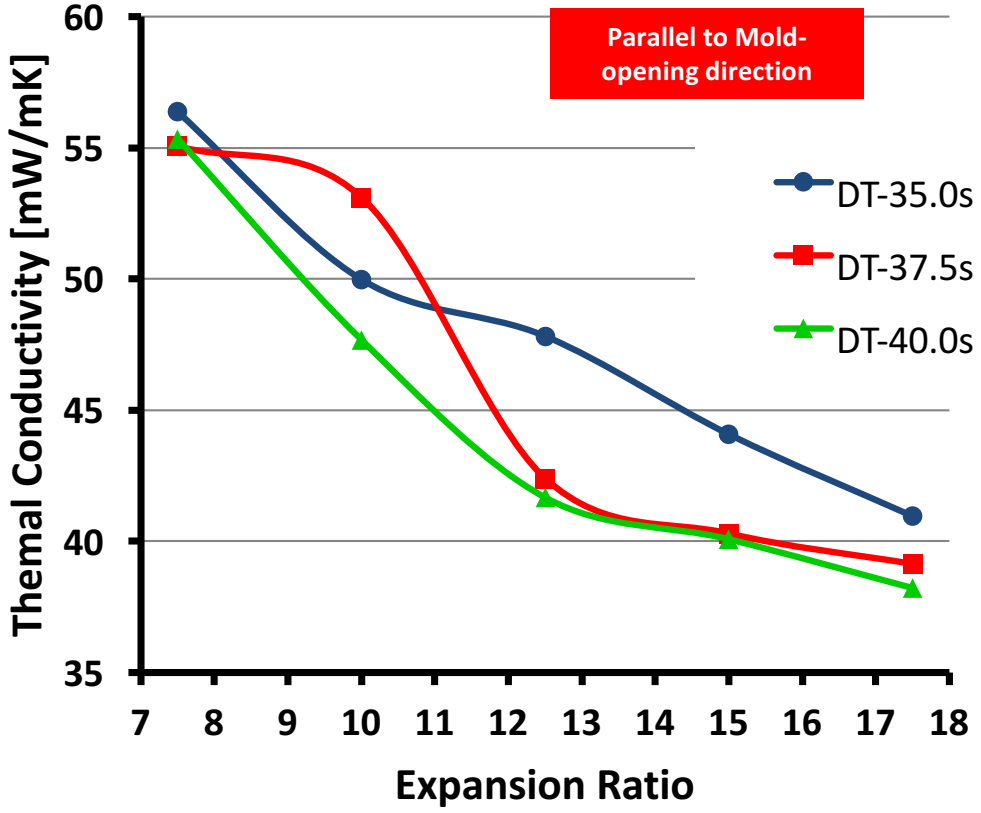


- Thermal conductivity is increased as the expansion ratio increase

Results and discussion

- Thermal insulation properties
  - Effect of expansion ratio (Mold-opening distance) on thermal conductivity

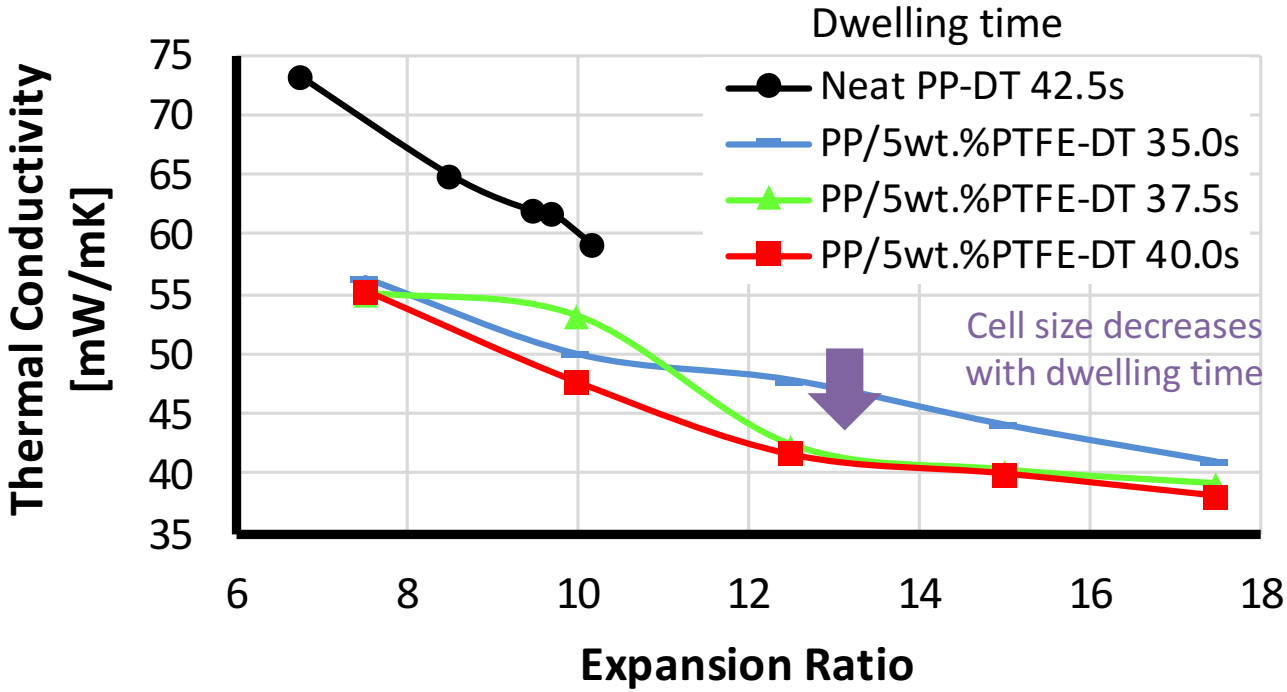




- Thermal conductivity is decreased as the expansion ratio increase

Results and discussion

- Thermal insulation properties



- Presence of fibrillated PTFE enables FIM PP parts to attain higher quality foam structures (more uniform, higher expansion, much smaller cell sizes)
  - FIM PP/PTFE parts possess better thermal insulation properties

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Summary

- Effect of PTFE on rheological properties
  - Increased G', G", and η* at low frequency range
  - Improved the strain hardening behavior
  - Increased crystallization temperature and enhanced Heterogeneous crystal nucleation
- Effect of PTFE on cellular structure
  - Decreased the cell size from 600µm to 20µm
  - Increased the cell density from 10^4 cells/cm^3 to 10^9 cells/cm^3
- Effect of cell structure on thermal conductivity
  - Dramatically enhanced the thermal insulation, decreasing thermal conductivity from 70 mW/mk to 40 mW/mk