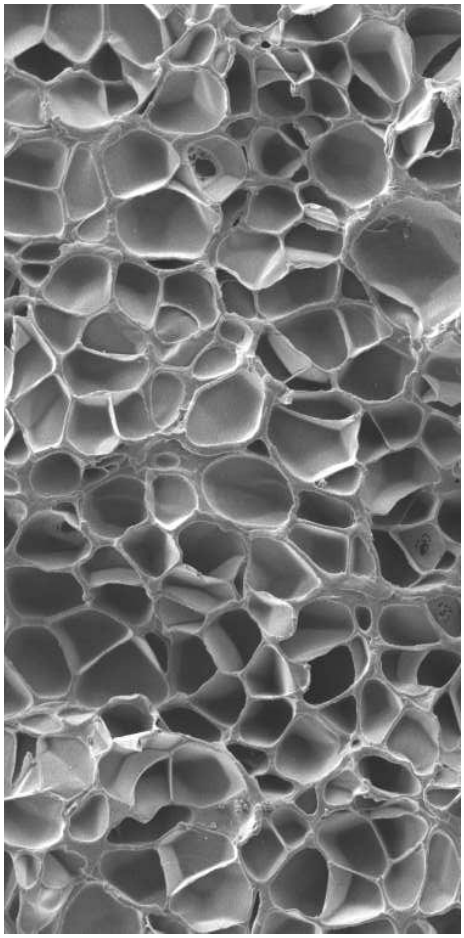

Crystallinity Effects in Polylactic Acid (PLA) Based Foams

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Outline

- Background and objectives
- Methods
  - materials
  - foam processing
  - characterisation
- Results
- Conclusions

Poly(lactic acid) (PLA)

- Corn → Dextrose → Lactic acid → Lactide → PLA

- D/L ratio controls:
  - crystallinity
  - crystallisation rate
  - melting temperature

- T_g around 55-60°C

The Biopolymer Network (BPN) process

Liquid CO_2 impregnation

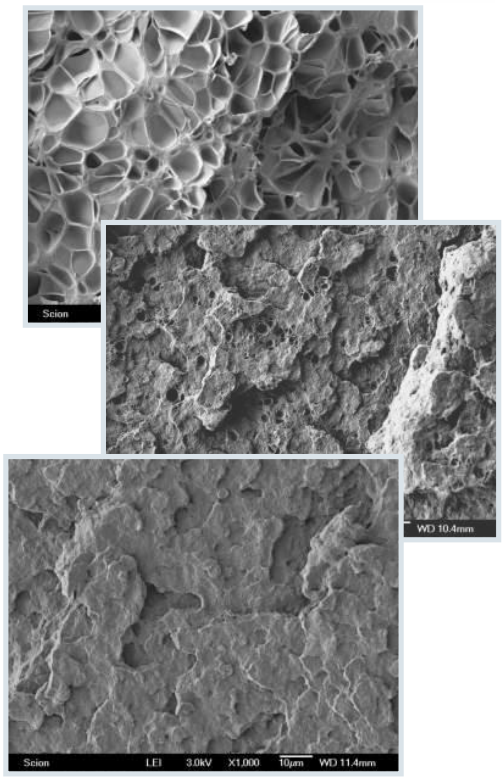
Pre-foaming

Moulding

Patent # WO 2008/093284 A1

Crystallinity and foaming

- Higher crystallinity in the starting material means:
  → lower CO_2 solubility
  → higher matrix stiffness
  → more difficult foaming
- CO_2 induces crystallisation
- Expansion also generates crystallinity



Benefits of crystalline PLA foams

- Effect on mechanical properties?
- Higher dimensional stability?
- Wider processing windows?

Materials

- Four PLAs with various D-contents
- Samples extruded in 15 mm x 2 mm rods

PLA	D-content (%)	Crystallisation $t_{1/2}$ @ 100°C (minutes)
SC1	1.4	3-4
SC2	4.3	22-23
SC3	7.7	121-124
AM	11.8	-

Foam processing

Liquid CO_2 impregnation

Foaming in hot water targeting 40 and 60 g/L

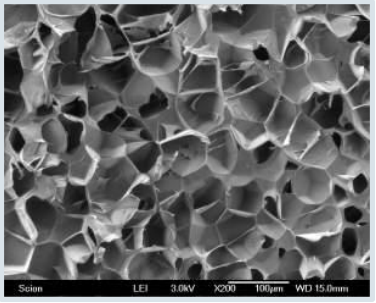
Characterisation

- Density (fluid displacement)
- Scanning Electron Microscopy (SEM):
  - cross-sections
  - surfaces
- Differential Scanning Calorimetry:
  - 20 to 200°C at 5°C/minute
- Dimensional stability:
  - relative volume change over 24 hours at 70°C

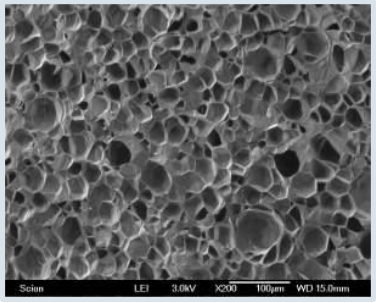
Mechanical testing

- Samples foamed between two steel plates and cut into rectangular specimens (35 x 4 x 3 mm)
- Three-point bending (DMTA):
  - 28 mm support span
  - 10% per minute strain rate
- Modulus by linear regression

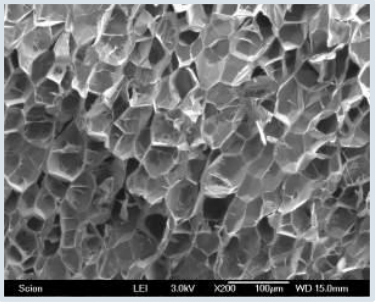
Foams cross-sections (SEM)



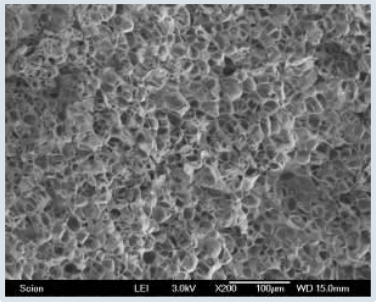
SC1



SC2



SC3

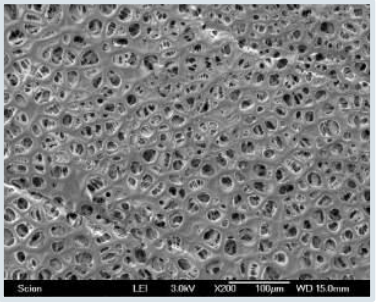


AM

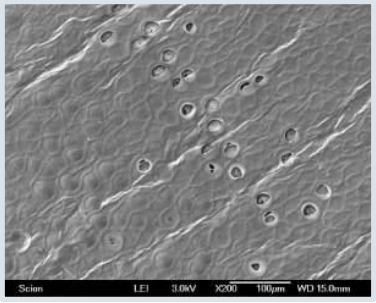
40 g/L

- Closed-cells
- Higher cell density in AM PLA

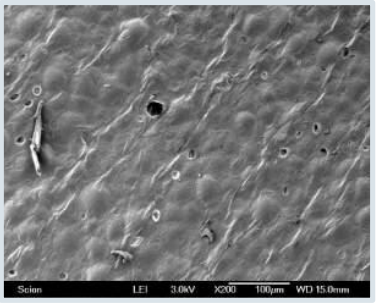
Foams skins (SEM)



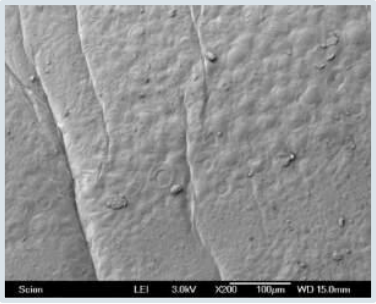
SC1



SC2



SC3

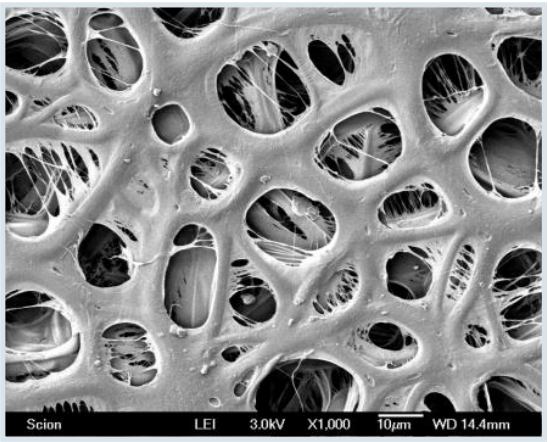


AM

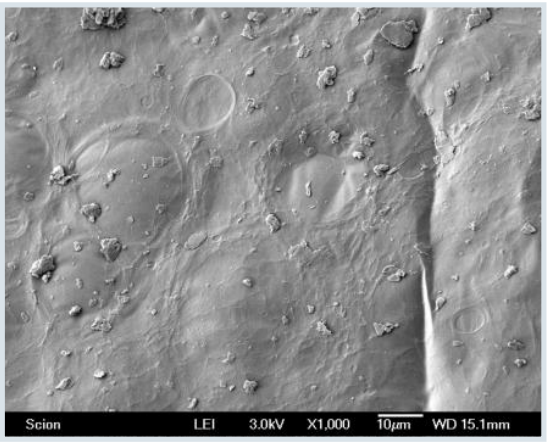
40 g/L

- Porous surface in SC1 PLA
- Smooth surface in AM PLA

Foams skins (SEM)



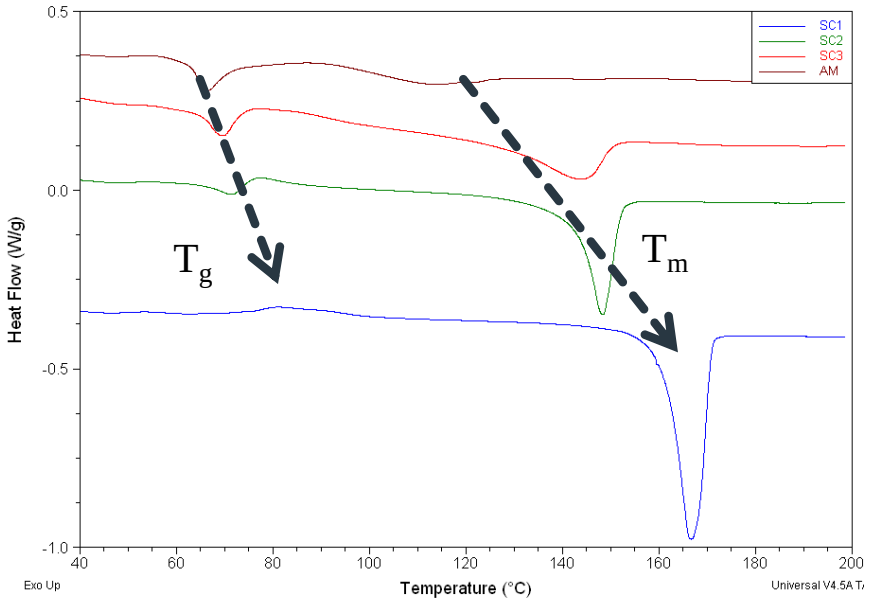
SC1



AM

- Higher open-cell content in SC1 foams?
- Cell wall rupture due to small crystals

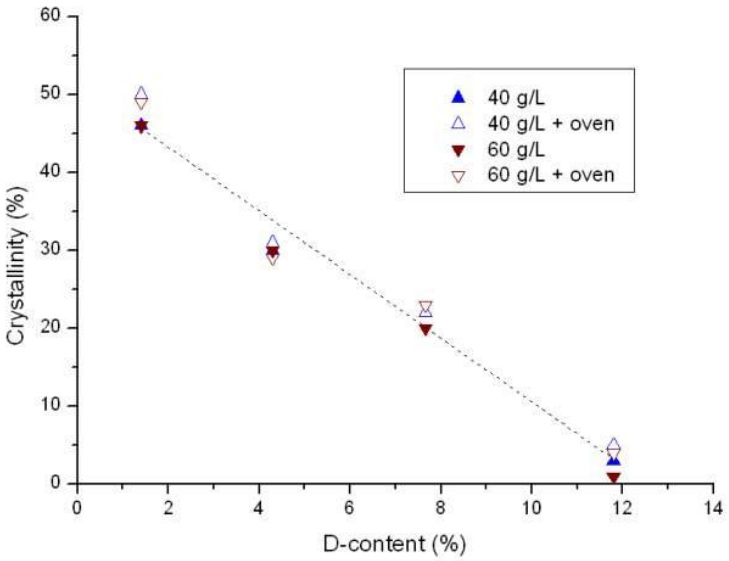
Thermal behaviour



Foamed at 60 g/L

- Increasing T_m and T_g with decreasing D-content

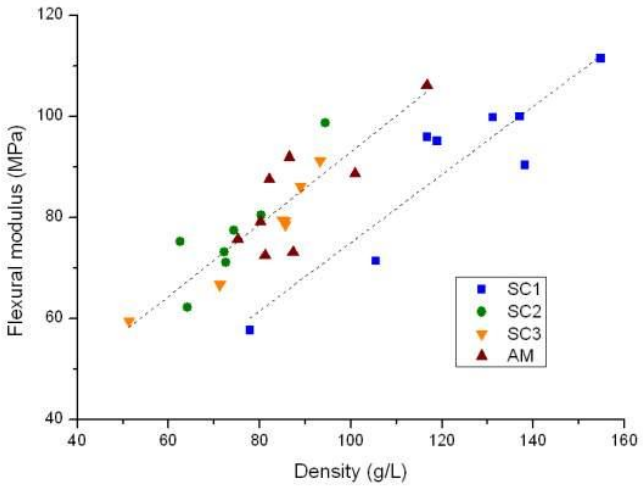
Thermal behaviour



Crystallinity calculated from DSC

- Linear relationship
- No density effect
- Slight increase due to oven-treatment

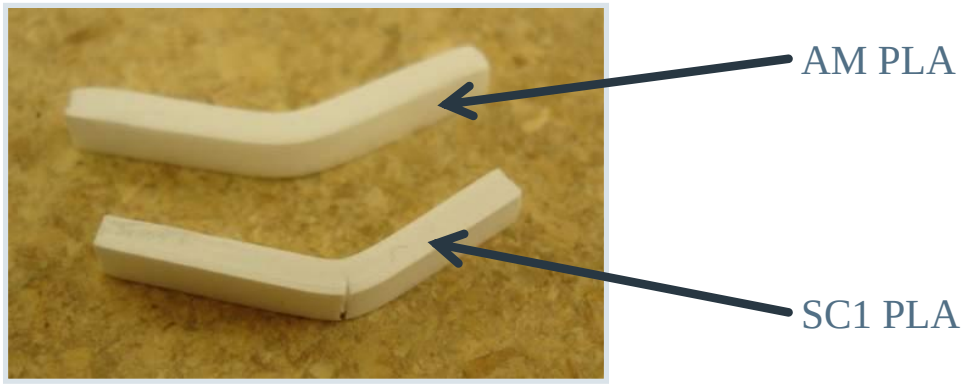
Mechanical testing



- SC2, SC3 and AM show the same behaviour.
- SC1 PLA foam has lower modulus

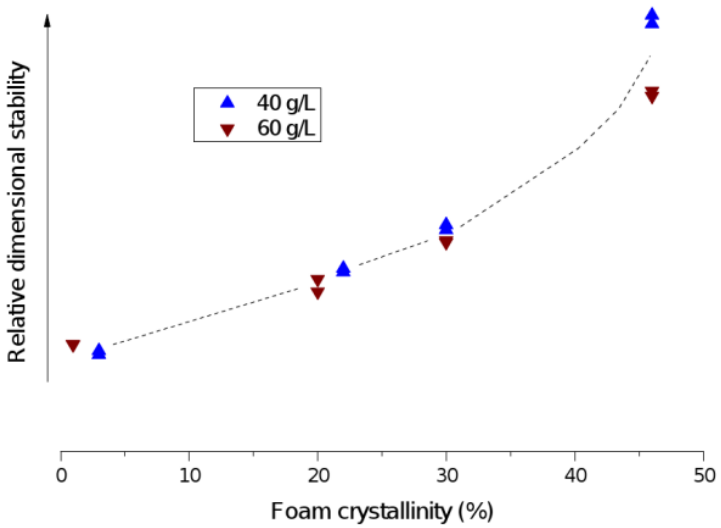
  → due to open-cell content?

Mechanical testing



- Fracture occurred in some SC1 PLA samples

Dimensional stability (70°C for 24 hours)



- Not a linear relationship
- Large increase in stability above 40% crystallinity
- Significant density effect

Conclusions

- PLAs with a wide range of D-contents can be foamed using the BPN process.
- Cellular structure and mechanical properties are affected by the PLA grade used.
- Up to 50% crystallinity in the foams in the foams made by the BPN process.
- Increased crystallinity can significantly improve dimensional stability.

Acknowledgements

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