Processing and Characterization of Solid and Microcellular PHBV/PBAT Blend and its RWF/Nanoclay Composites

Alireza Javadi

Department of Materials Engineering,
University of Wisconsin-Milwaukee,
Milwaukee, USA

UNIVERSITY of WISCONSIN
UWMILWAUKEE

64th International Convention
Forest Products Society
June 20-22, 2010
Madison, Wisconsin, USA

Research Team

- Prof. Shaoqin (Sarah) Gong (Advisor)
  - Department of Biomedical Engineering, University of Wisconsin-Madison, USA
- Yottha Srithep, Jungjoo Lee and Prof. Lih-Sheng Turng
  - Department of Mechanical Engineering, University of Wisconsin-Madison, USA
- Craig Clemons
  - Forest Products Laboratory, United States Department of Agriculture, Madison, Wisconsin, USA
- Srikanth Pilla
  - Department of Civil & Environmental Engineering, Stanford University, California, USA

Background Motivation

- Almost 90% of plastics produced from petroleum-based resources
  - Depleting non-renewable resources
  - Instability of oil price
  - Environmental concerns
    - Landfills disposal
      - Limited space
      - Non-biodegradability
    - Incineration
      - Toxic gases emission
    - Recycling
      - Challenges
        - Retaining material properties
        - Unfavorable economic factors
        - Technology under development

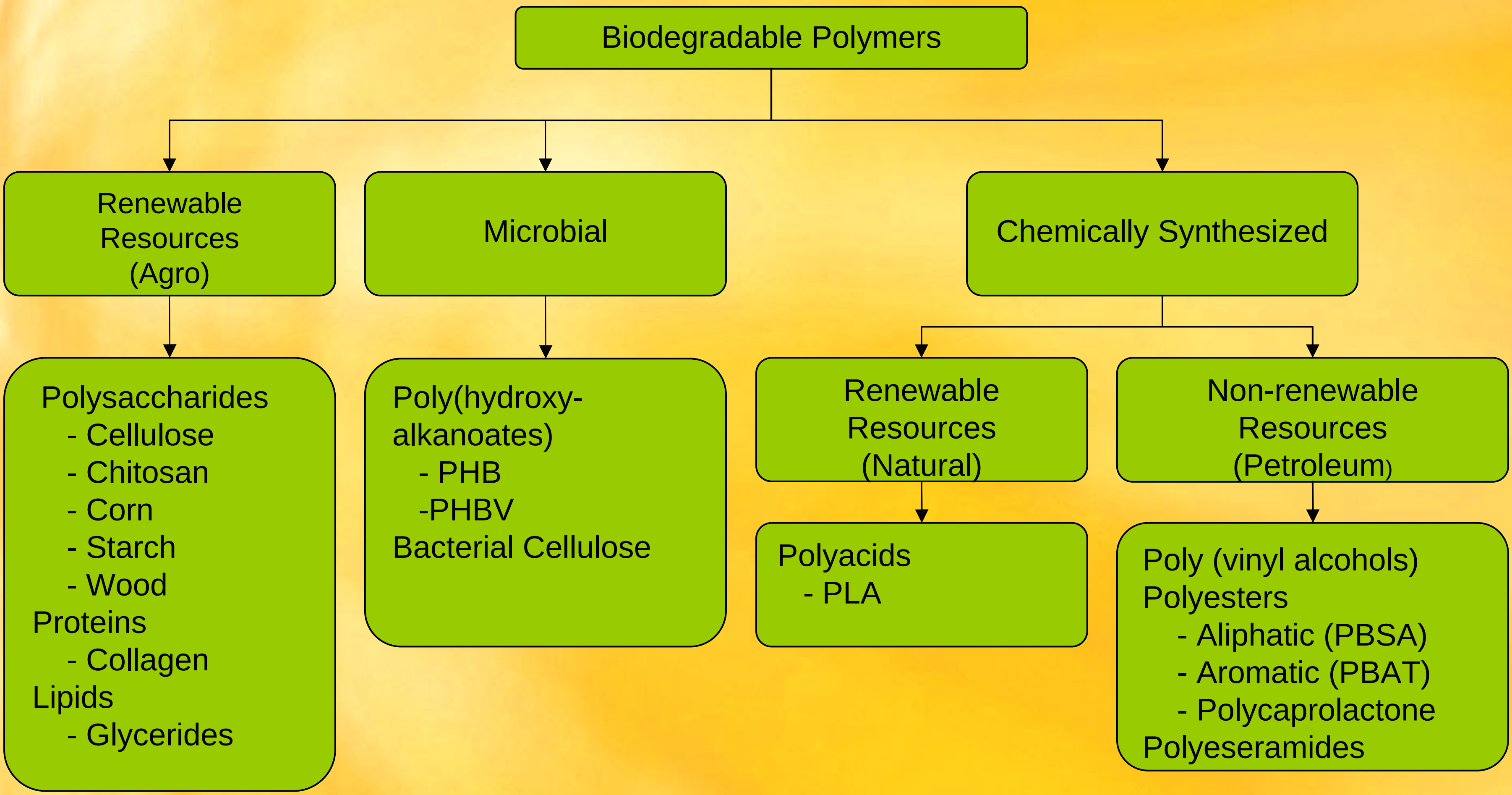
Biodegradable Polymers

- Green Plastics
  - Potential alternatives for petroleum-based non-degradable polymers
    - Biodegradable
    - From renewable resources (plants and crops)
      - Sustainability
    - Environmentally friendly
      - Reducing the Carbon footprint
    - Biocompatible
      - Potential application in Biomedical industries
  - Increasing demand for biodegradable plastics in US
    - From 285 million pound in 2007 to 630 million pounds in 2010

UNIVERSITY of WISCONSIN
UWMILWAUKEE

64th International Convention
Forest Products Society
June 20-22, 2010
Madison, Wisconsin, USA

Biodegradable Polymers

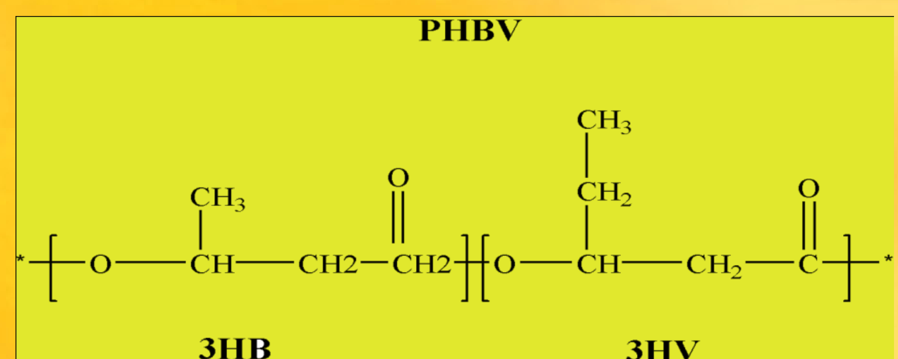


Biodegradable Polymers

- Potential Applications
  - Packaging
    - Food packaging, fast food service-ware
  - Automotive
    - Exterior, interior
  - Biomedical
    - Bone plates, osteosynthetic materials, surgical sutures
  - Agriculture
    - Composting bag, mulch film
- Challenges
  - Inferior material properties
  - High cost
  - Lack of infrastructure for post consumption composting treatment
  - Difficult to process
    - Thermal degradation
    - Narrow processing window

Poly(hydroxyalkanoates) (PHAs) and Their Challenges

- Family of linear thermoplastic polyesters
- Poly(3-hydroxybutyrate) (PHB) and its copolymer poly(3-hydroxybutyrate-co-3-hydroxyvalerate) (PHBV)
  - Linear thermoplastic polyesters produced by controlled bacterial fermentation process
  - High crystallinity
  - High modulus
  - Fully biodegradable
  - Similar material properties to those of polyolefins
  - Drawbacks
    - High cost
    - Brittleness
    - Low elongation at break
    - Sensitive to thermal degradation

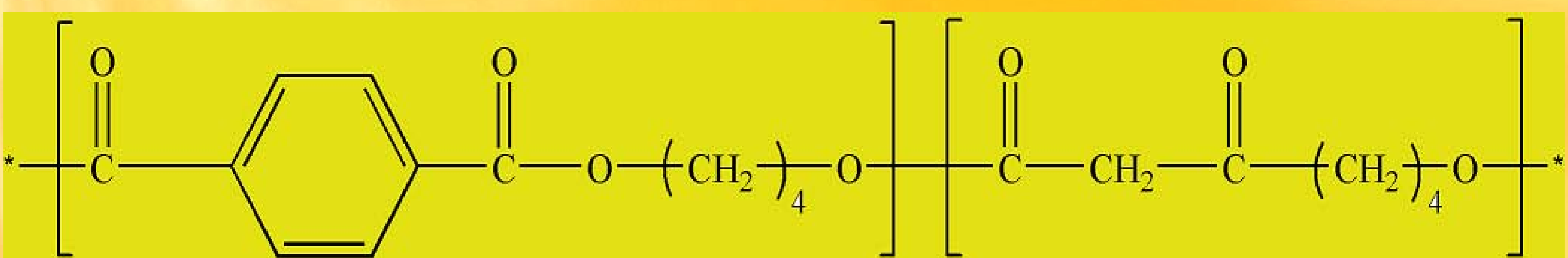


Possible Solutions to Meet Drawbacks

- Special additives
  - Plasticizers
  - Chain extenders
  - Hyperbranched polymers
- Biobased polymer blends
  - PBAT
  - PPC
  - PBSU
- Nanoparticles
  - Nanoclay (nanoplatelets and nanotubes)
  - Carbon nanotubes
- Natural fibers
  - Recycled wood fibers
  - Lignocellulosic flour
  - Pineapple fibers
  - Kenaf fibers
  - Coir fibers
- Microcellular processing

PBAT

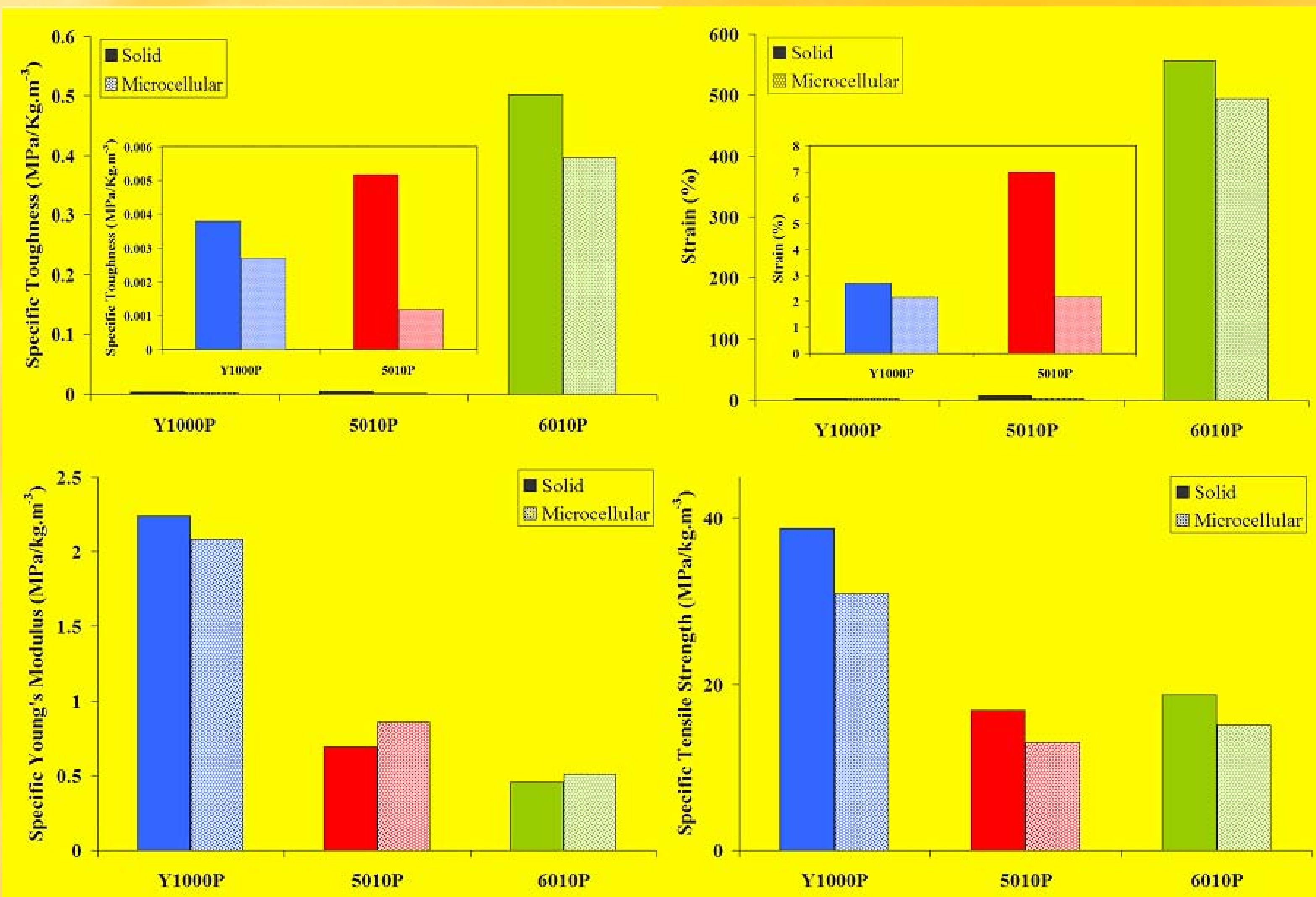
- Poly(butylene adipate-co-terephthalate)
- Aliphatic–aromatic co-polyester
- Fully biodegradable
  - Within a few weeks with the aid of naturally occurring enzymes
- Low modulus and low tensile strength
- High toughness and strain-at-break
- One of the best candidate for increasing PHBV toughness and strain at break)



UNIVERSITY of WISCONSIN
UW MILWAUKEE

64th International Convention
Forest Products Society
June 20-22, 2010
Madison, Wisconsin, USA

Previous Study

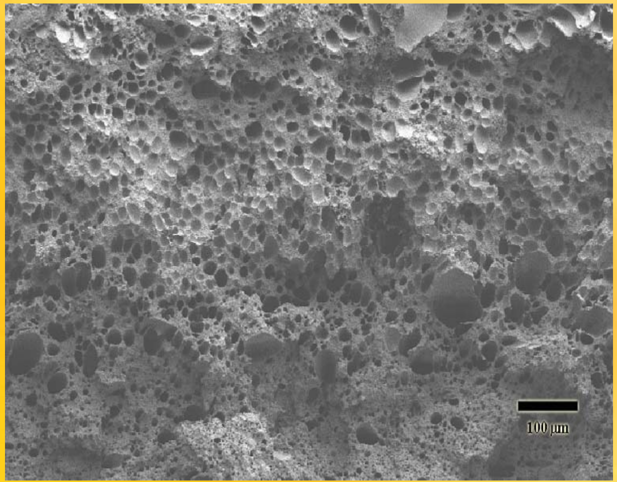


Inorganic and Organic Fillers

- Nanoclay (Cloisite® 30B)
  - Lower thermal expansion coefficient
  - Higher Young's modulus
  - Improving thermal stability
- Recycled wood fiber
  - Biodegradability
  - Renewability
  - Low cost
  - Low density
  - High specific strength and stiffness
  - Less wear on machinery
- Coupling Agents (Silane-treatment)
  - Reducing the hydrophilicity and moisture absorption
  - Improving interfacial bonding between polymer matrix and reinforcing fiber
  - Low cost

Microcellular injection Molding Technology

- Novel foaming technology
- Commercialized by Trexel inc. under the name Mucell®
- Process steps
  - Injection of supercritical fluids (SCF) into the barrel and formation of single phase gas-polymer solution
  - Cell nucleation with rapid pressure drop after nozzle
  - Cell growth



UNIVERSITY of WISCONSIN UWMILWAUKEE

64th International Convention
Forest Products Society
June 20-22, 2010
Madison, Wisconsin, USA

Microcellular injection Molding Technology

- Advantages
  - Part weight reduction
  - Economically favorable
  - Excellent dimensional stability
  - Using supercritical fluids (SCFs) of N_2 or CO_2 as physical blowing agent which do not present environmental hazardous
  - Less materials and energy
  - Shorter processing time
  - Improved component properties

UNIVERSITY of WISCONSIN UW MILWAUKEE

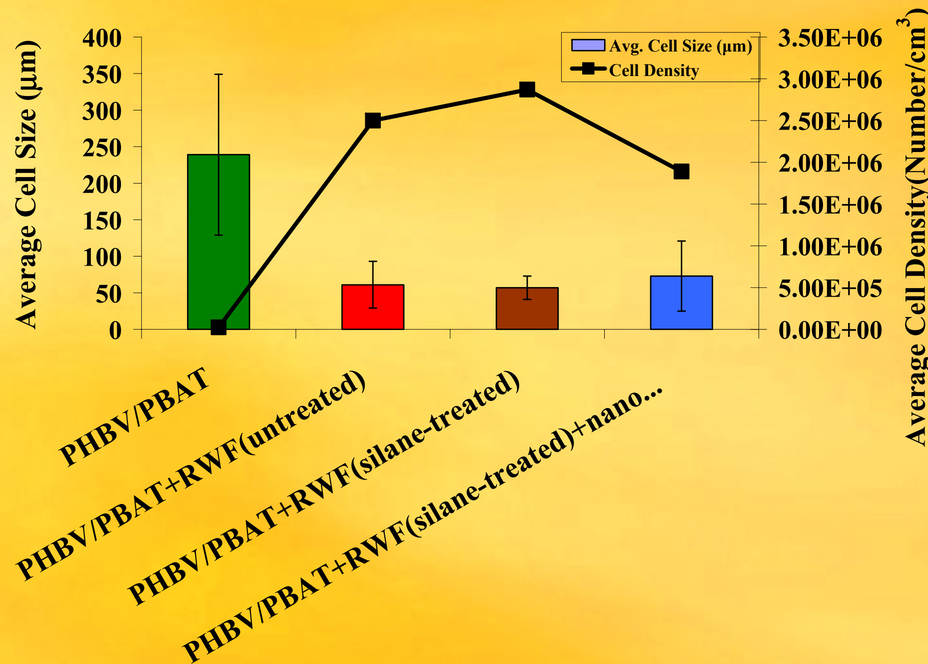
64th International Convention
Forest Products Society
June 20-22, 2010
Madison, Wisconsin, USA

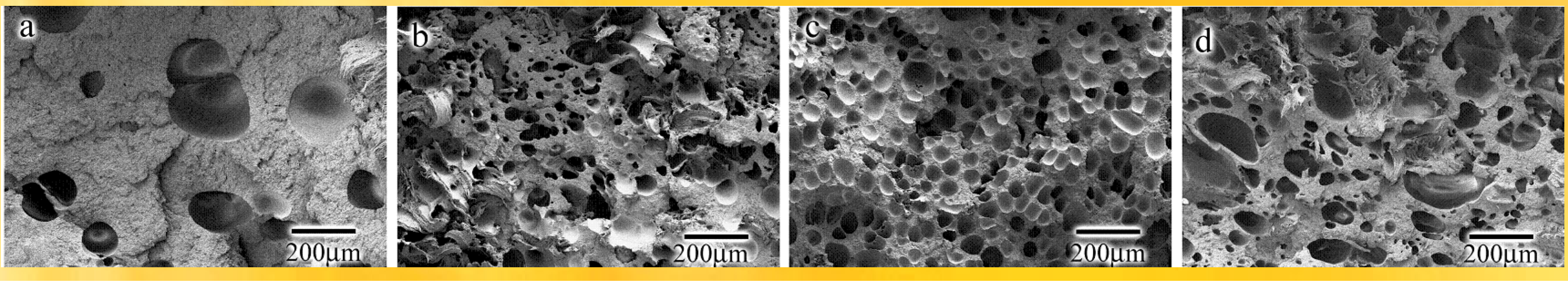
Formulations

- PHBV/PBAT
- PHBV/PBAT+10% untreated-RWF
- PHBV/PBAT+10% silane-treated-RWF
- PHBV/PBAT+10% silane-treated-RWF+2% nanoclay

SEM analysis of Microcellular Components

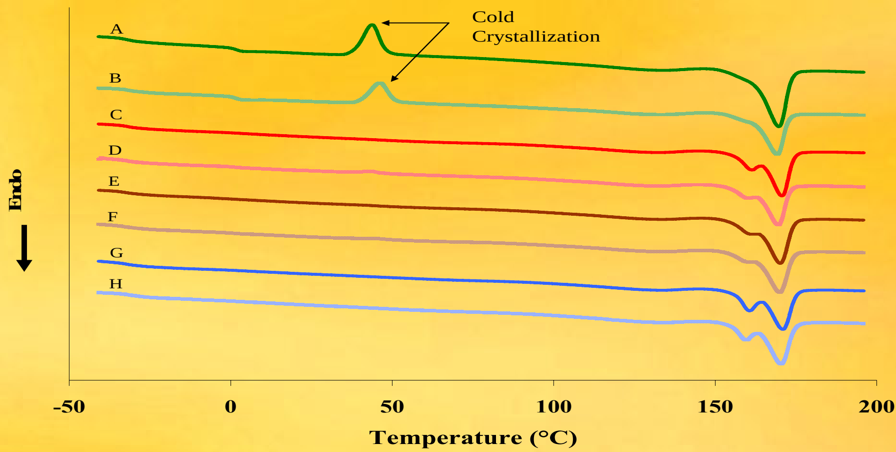
- Average cell diameter of cells decreased with addition of (untreated and treated) RWF.
- Cell density increased with addition of (untreated and treated) RWF.
- The standard deviation (SD) of cell size became smaller with addition of RWF which shows more uniformity in cell sizes.
- No significant change in the cell size or cell density was observed with addition of nanoclay.





Crystallization

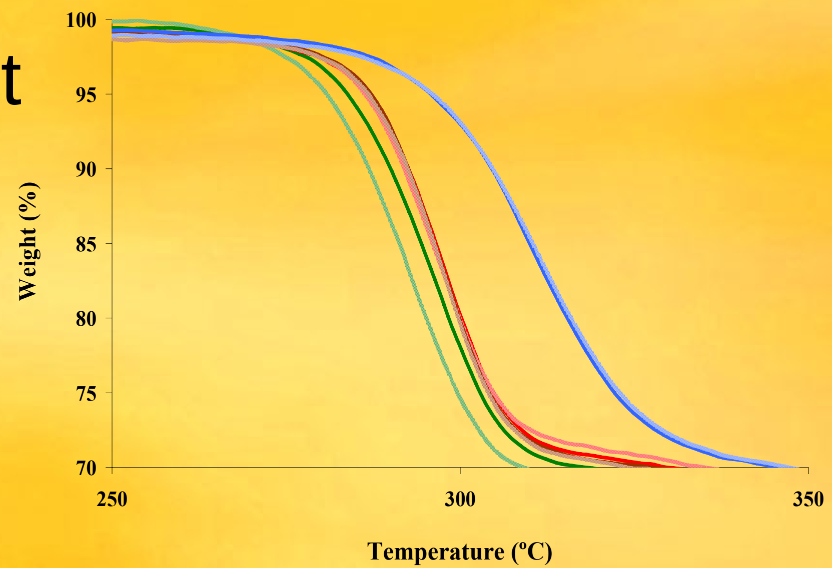
- Cold crystallization peaks vanished for composite specimens
  - ❖ No more amorphous regions that had the ability to crystallize in those samples
- Crystallinity enhancement with addition of RWF
  - ❖ 20% for solids and 27% for microcellular
- Microcellular samples had lower crystallinity compared to solid samples.
- Fiber treatment method did not show any change in the degree of crystallinity.
- Further enhancement with nanoclay

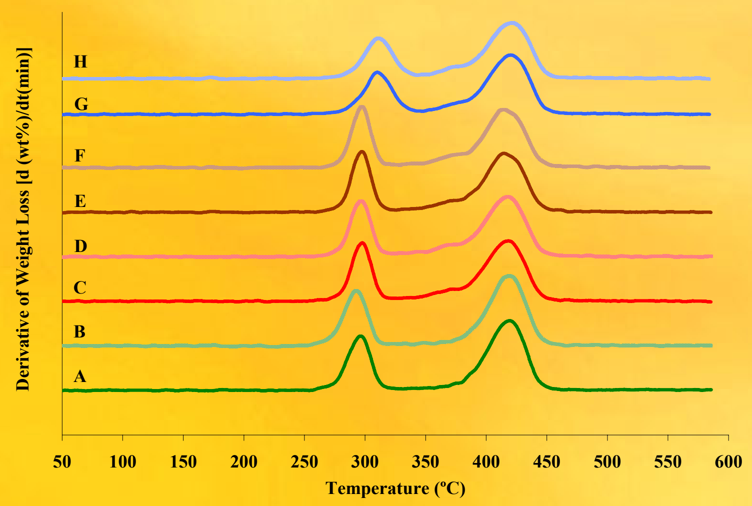


	Sample	Crystallinity (%)
Solid	PHBV/PBAT	43
	PHBV/PBAT+10% untreated-RWF	63
	PHBV/PBAT+10% silane-treated-RWF	63
	PHBV/PBAT+10% silane-treated-RWF +2% nanoclay	66
Microcellular	PHBV/PBAT	32
	PHBV/PBAT+10% untreated-RWF	59
	PHBV/PBAT+10% silane-treated-RWF	59
	PHBV/PBAT+10% silane-treated-RWF +2% nanoclay	62

Thermo-Gravimetric Analysis

- Thermal stability enhancement with addition of nanoclay
  - Nanoclays can act as a heat barrier
- Slight thermal stability enhancement with addition of RWF
  - Untreated and treated
  - Due to the presence of certain minerals in RWF which do not decompose at higher temperatures



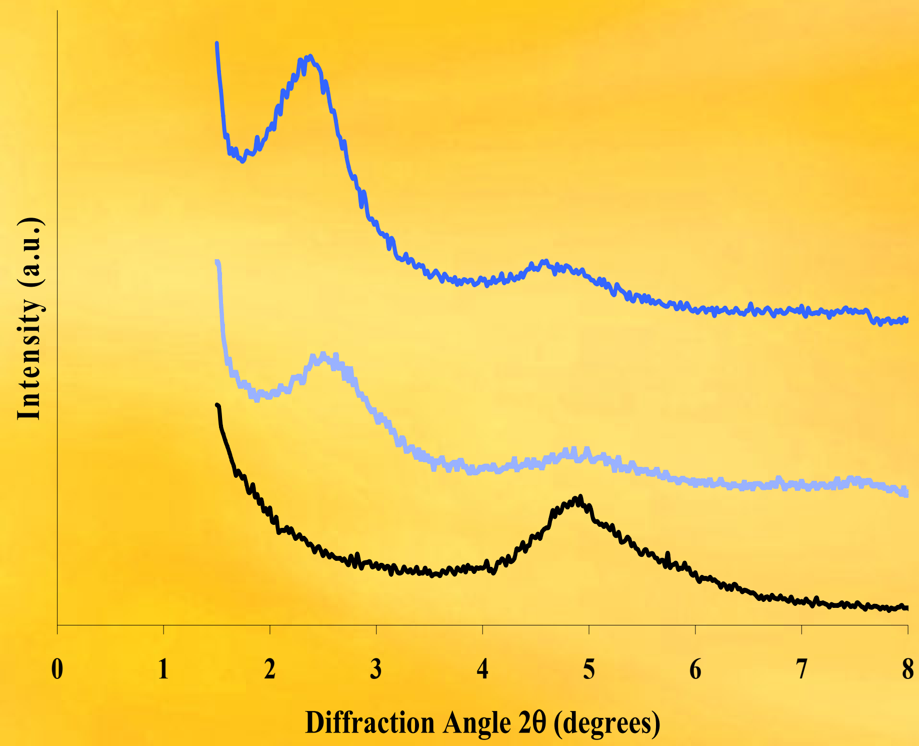


UNIVERSITY of WISCONSIN
UWMILWAUKEE

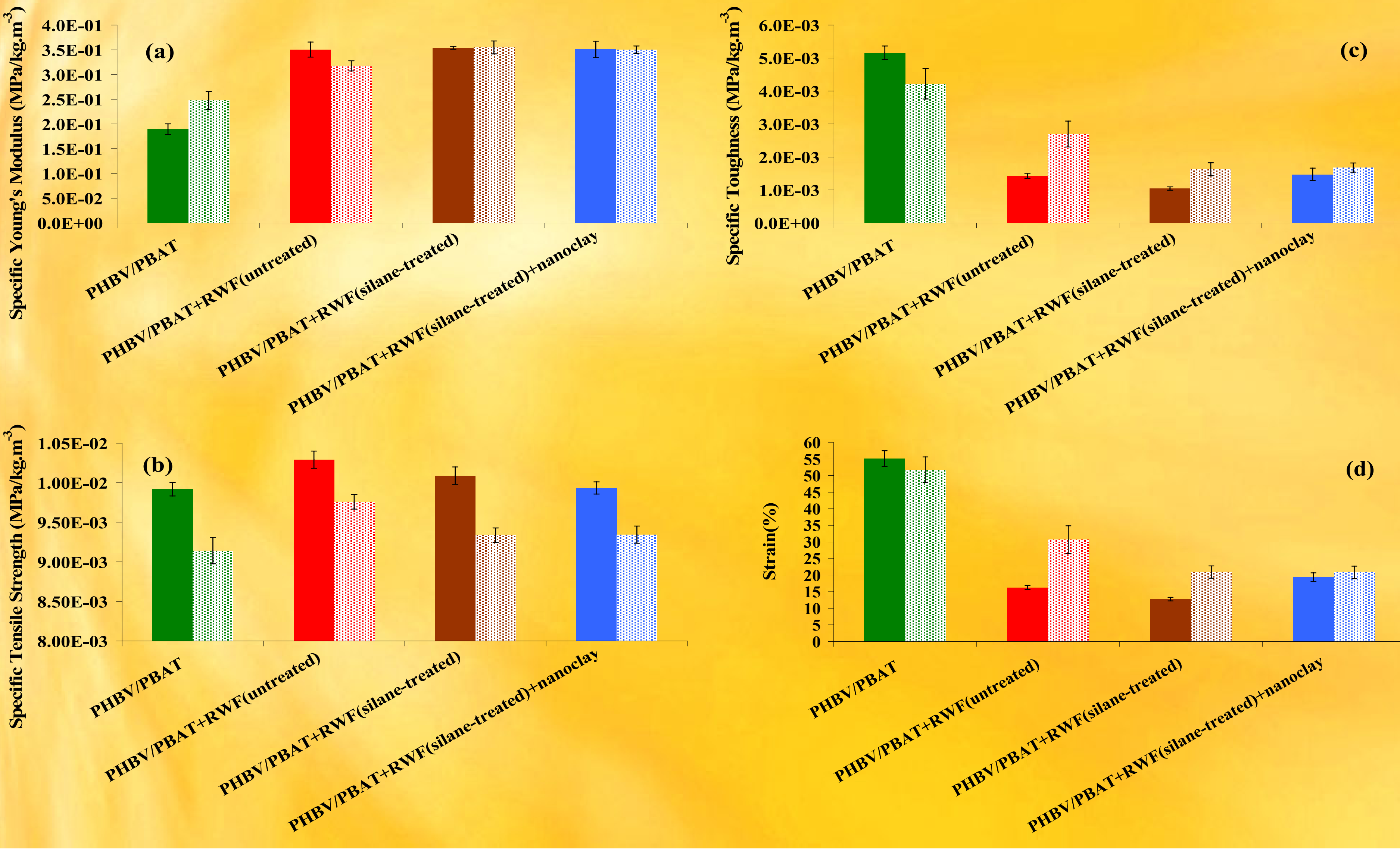
64th International Convention
Forest Products Society
June 20-22, 2010
Madison, Wisconsin, USA

Wide Angle X-ray Diffraction Analysis

- Nanoclay intercalation occurred in the PHBV/PBAT composites
- Broad peaks
  - $2\theta = 4.79^{o}$ for solid
  - $2\theta = 4.92^{o}$ for microcellular
  - Originate from the appearance of a new basal reflection corresponding to a larger gallery height



Tensile Properties



UNIVERSITY of WISCONSIN UWMILWAUKEE

64th International Convention
Forest Products Society
June 20-22, 2010
Madison, Wisconsin, USA

Conclusion

- Production of novel green composites with
  - Lower costs
  - Lighter weight
  - Improved thermal properties
  - Tailored mechanical properties

Acknowledgement

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

UNIVERSITY OF WISCONSIN SYSTEM
UW

Thank You For Your Attention

Questions?