Formaldehyde Free Wood-Based Composites Produced Through a Reactive Extrusion Process

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Issues Concerning Wood Composites

- Wood composite plants emit hazardous air pollutants (HAPs) to the environment.
- Formaldehyde is released over time from glued products.
- Public concerns about these issues cause new regulations to be proposed.

Recent Regulations

- US EPA enacted new rules limiting emissions of HAPs from composite wood manufacturing facilities.
- This is likely to spur new research on alternative adhesives.

Alternatives to Synthetic Adhesives

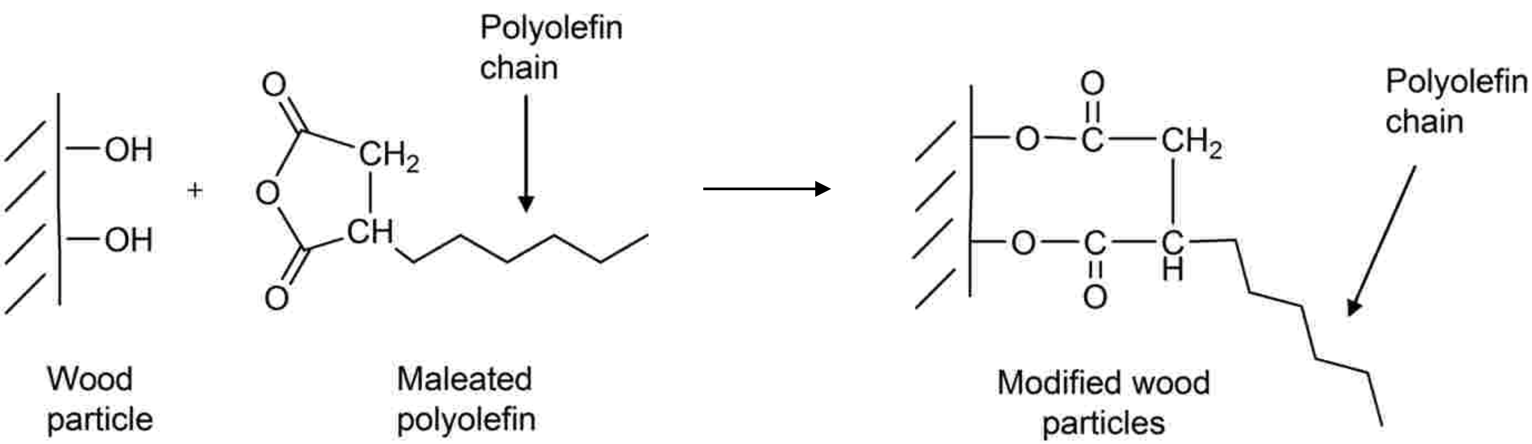
- Environmentally friendly wood adhesives
  - Low formaldehyde-to-urea molar ratio adhesives
  - Adhesives based on natural products
  - Additives to reduce formaldehyde release
- Binderless fiberboard
- Some alternatives have not been commercialized because of cost or property drawbacks.

Wood Modification

- Modification of wood particles with anhydride compounds for wood-plastic or composite applications has been demonstrated.
- Most prior approaches to modify wood particles used solvent processes.
- Solvents such as DMF, xylene, etc. are harmful to workers and environment.
- Solvent processes are inefficient, costly and not industrially viable.

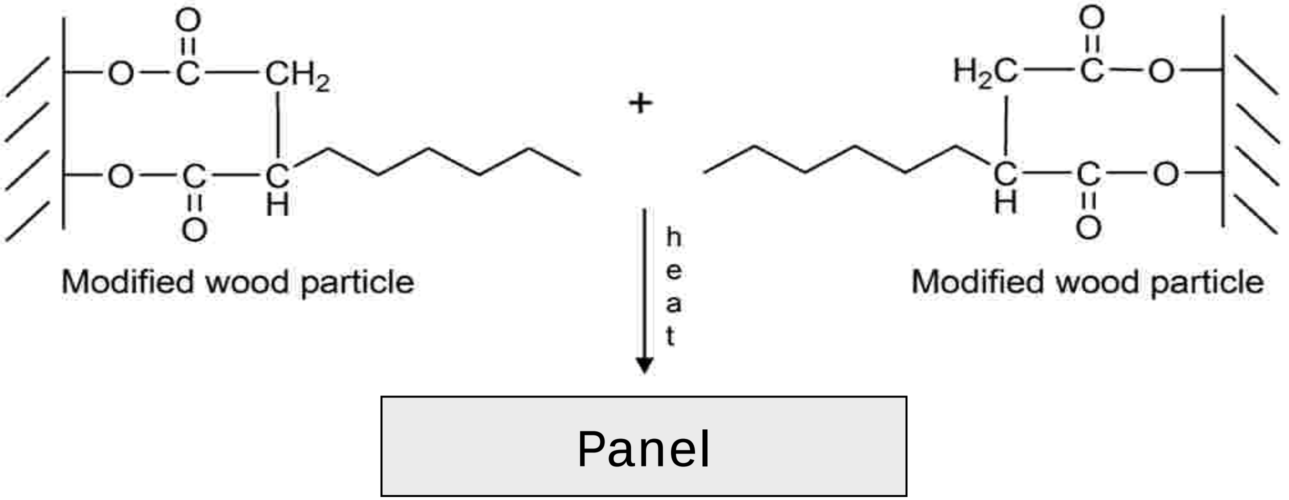
Hypothesis

- Maleated polyolefins will react with wood particles in a solvent-free reactive extrusion process.



Hypothesis (cont'd)

- Modified wood particles will bond together to form formaldehyde-free panels with no added adhesive.



Objective

- Use a reactive extrusion process to produce a formaldehyde-free binding system for wood composite products.

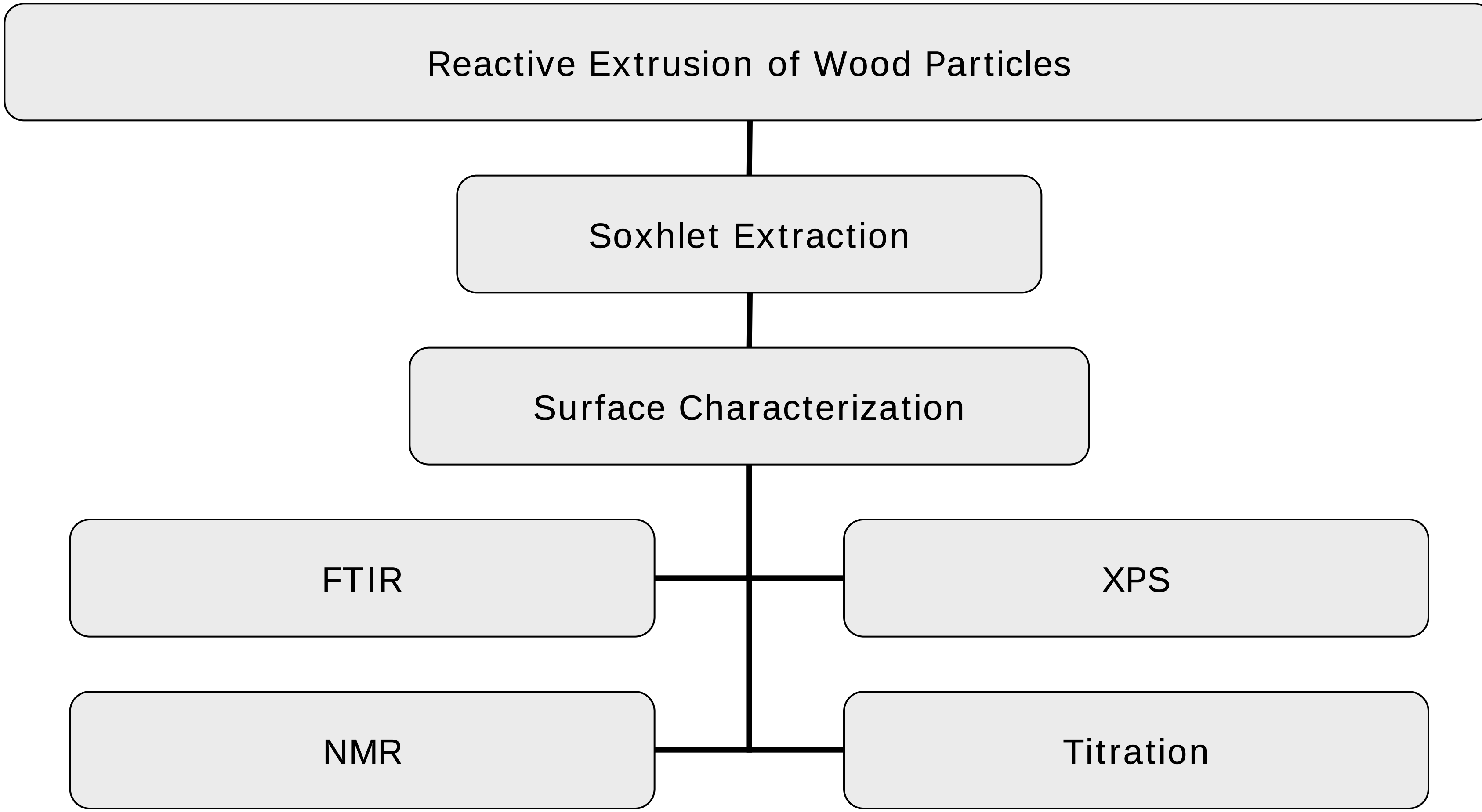
Requirements to Achieve Objective

- Modify wood particles in reactive extrusion;
- Characterize surface composition via spectroscopic and titration techniques;
- Manufacture wood composite panels and evaluate properties;
- Comparison with standards.

Part 1

Modification of wood particles in a reactive extrusion process and surface characterization

Research Scheme – Part 1



Material Composition

Ingredients	% Total in composite
Maple particles[1]	94 - 79
Maleated PE, PP	5 - 20
Hydrated zinc acetate	1%

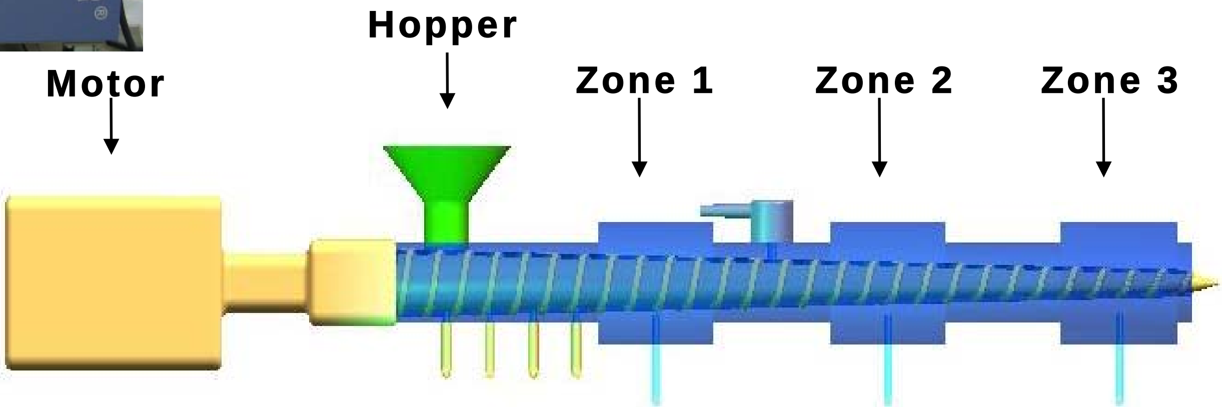
[1]maple of 125 micron size

Extrusion Processing Conditions

conical counter rotating twin screw extruder

- Rotational screw speed: 60 rpm
- Extruder barrel temperature: 160ºC

Extruder Diagram

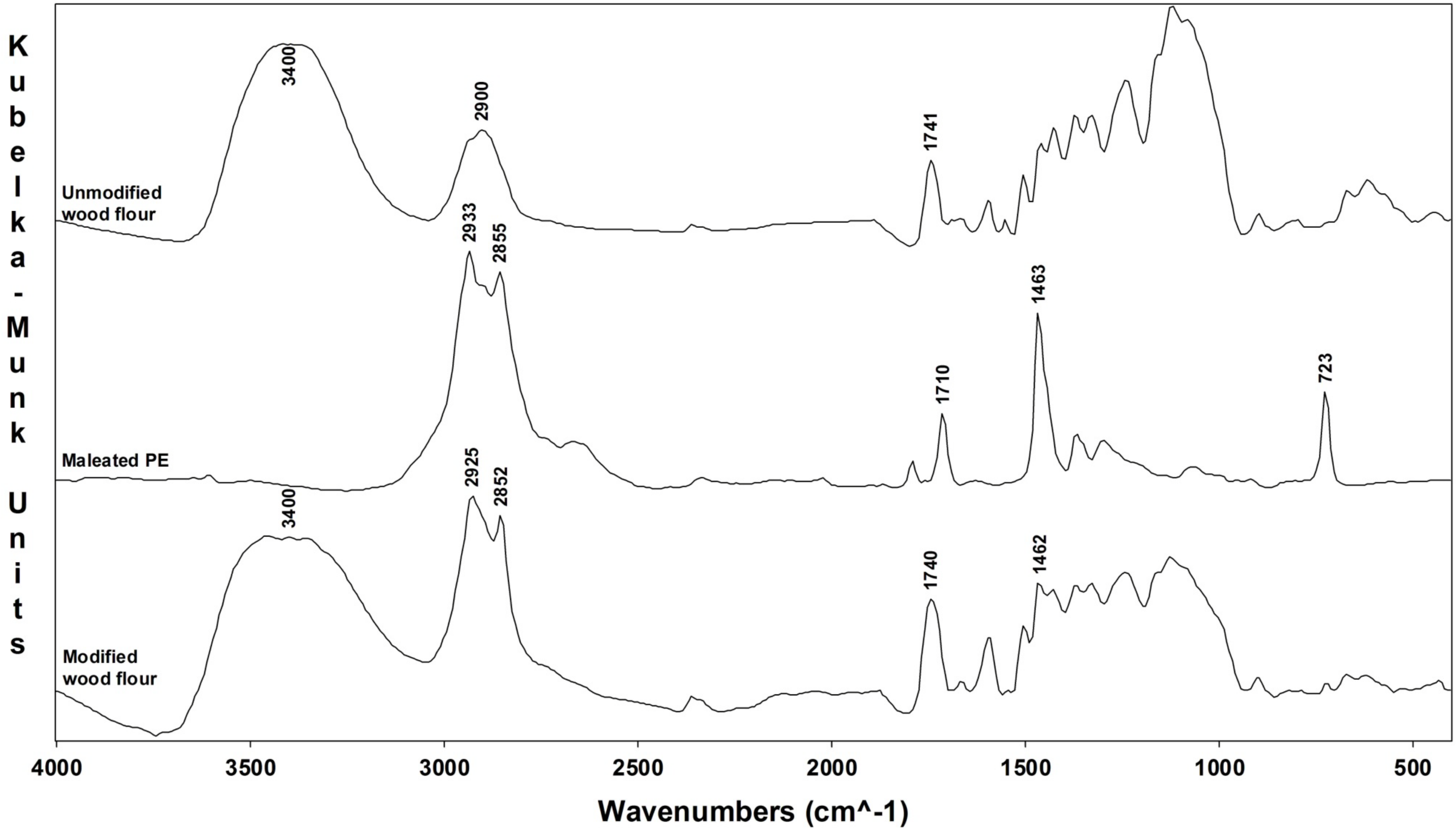


All zones maintained at a constant temperature for each test.

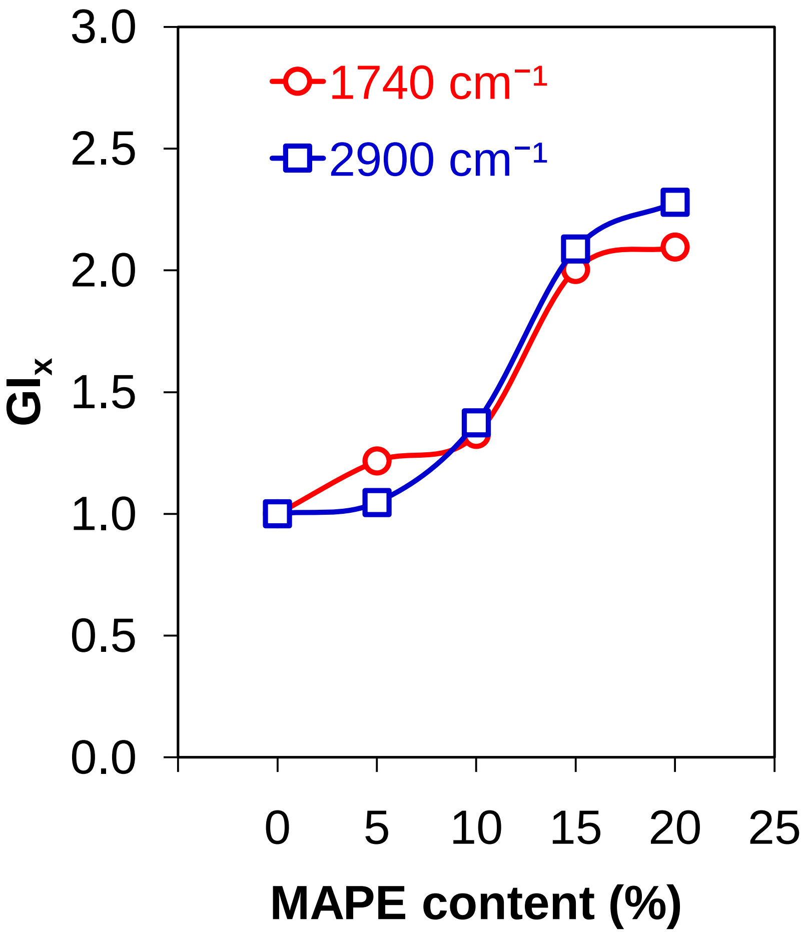
Surface Characterization of Modified Wood Particles

- Modified wood particles were Soxhlet extracted with xylene to remove unreacted coupling agent;
- Particles were oven dried and analyzed by FTIR and XPS.

FTIR Results



Grafting Index (GI_x)



$$GI_X = \frac{A_{X\,(Modified)}}{A_{X\,(Unmodified)}}$$

A_X : *integrated area of the peak*

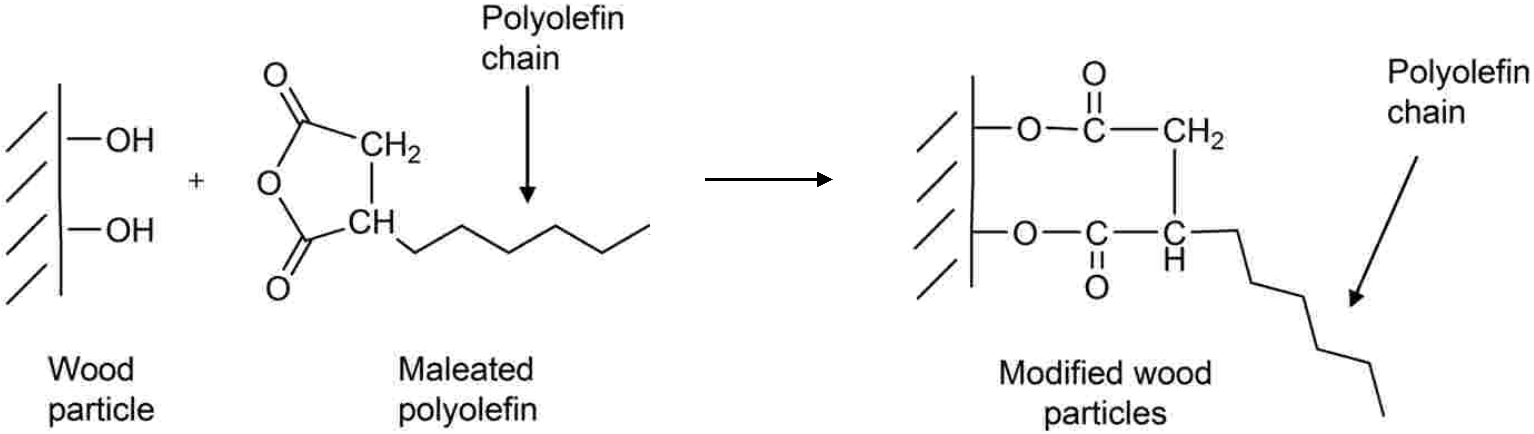
X : *peak at 1740 cm^{-1} or 2900 cm^{-1}*

XPS and Hydroxyl Index (HI)

Materials	O/C atomic ratios	Analysis of C_{1s} peaks (%)				OH index (HI)
		C1	C2	C3	C4	
Unmodified wood particles	0.47	39.75	51.20	8.46	0.58	1.00
Pure MAPE	0.11	87.13	7.71	5.16	0.00	0.15
Wood modified with 15% MAPE	**0.07**	92.80	**5.29**	1.91	0.00	**0.10**
Wood modified with 20% MAPE	**0.03**	95.08	**4.34**	0.58	0.00	**0.08**

$$HI = \frac{C2_{(\mathrm{mod}ified)}}{C2_{(un\,\mathrm{mod}ified)}}$$

Modification Scheme



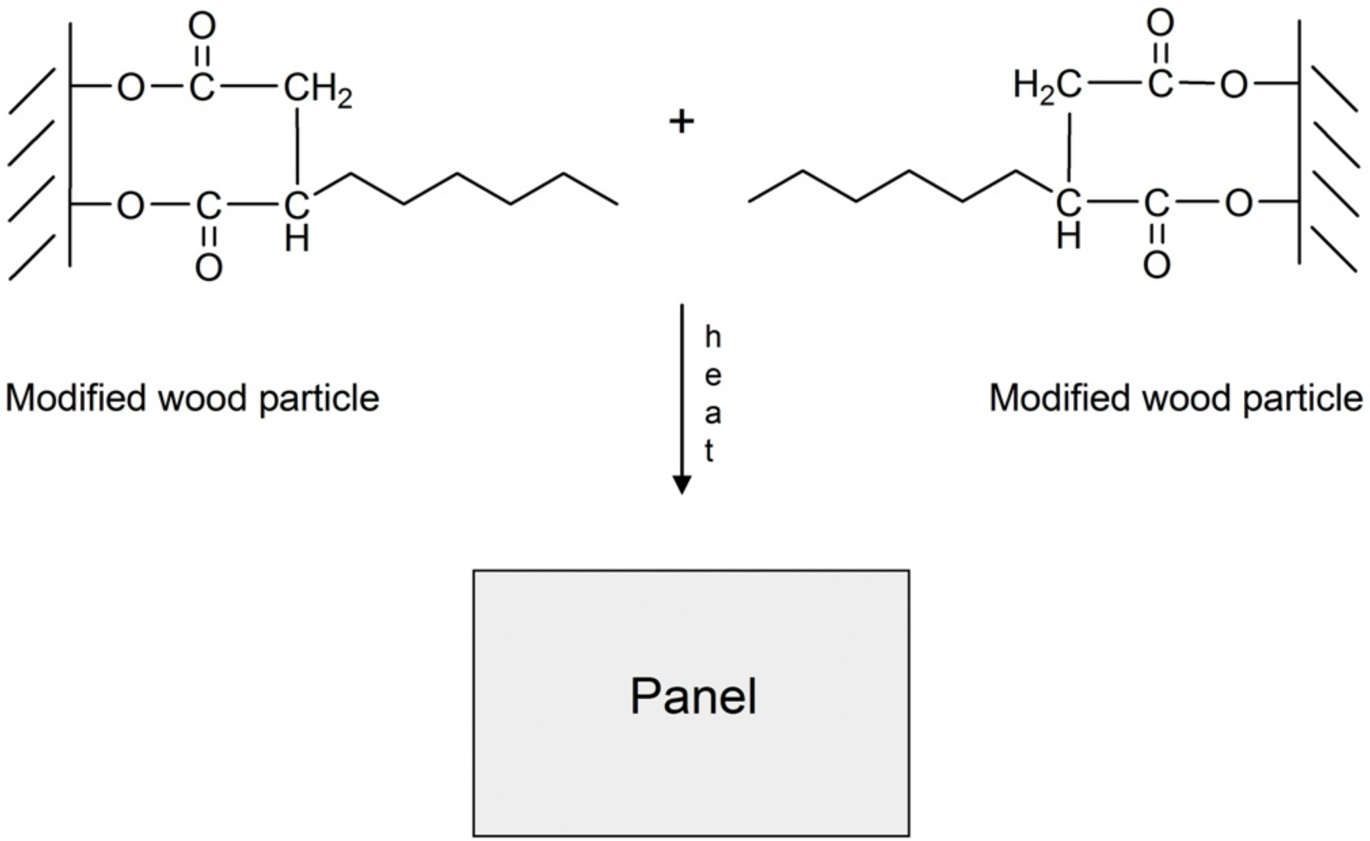
Part 1- Conclusions

- Maleated polyolefins were grafted to maple particles in a reactive extrusion process;
- Surface characterization data verified the reaction between the wood particles and maleated polyolefins.

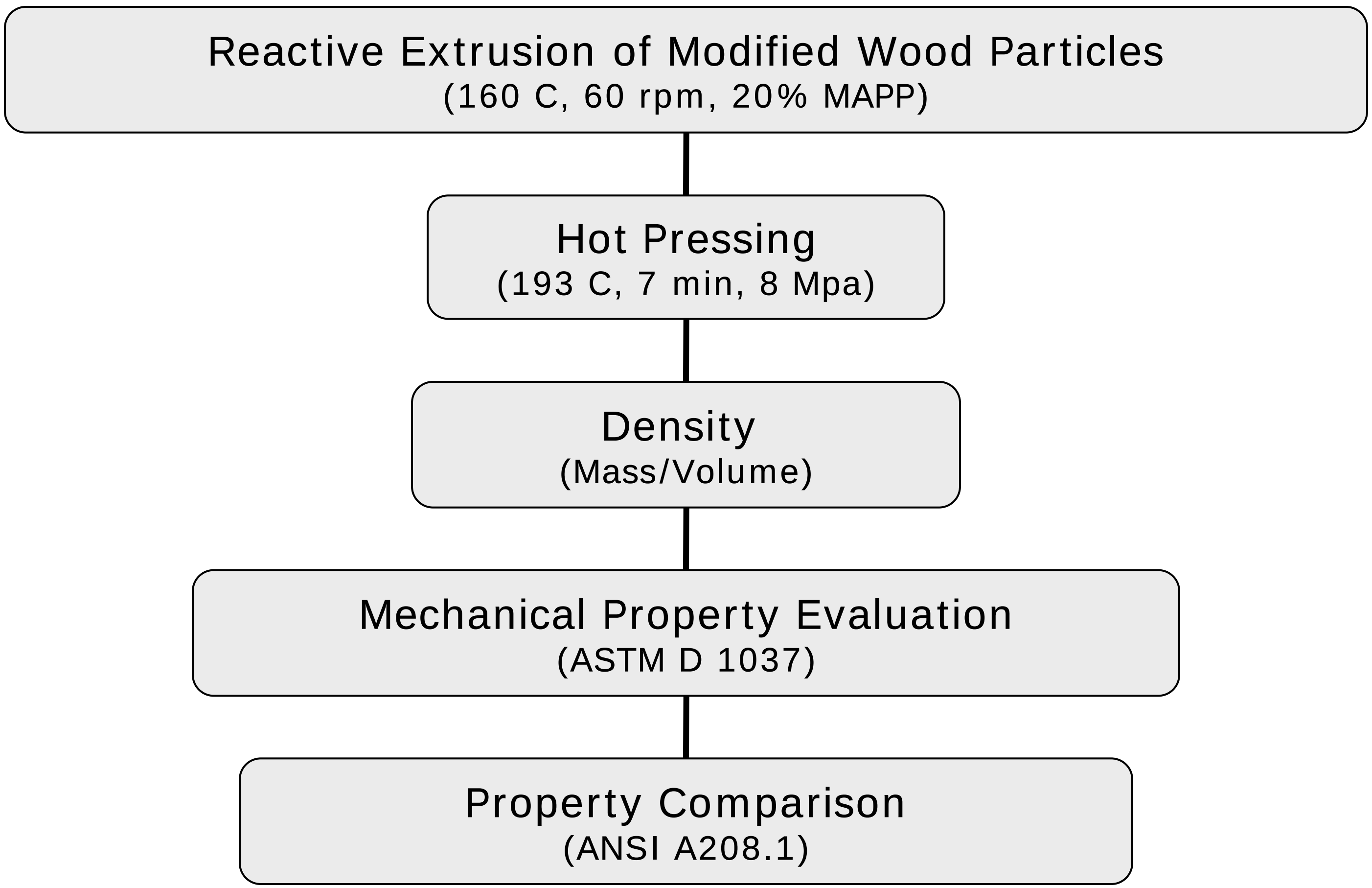
Part 2

Panel manufacture and property evaluation

Particle-Particle Bonding Scheme



Research Scheme - Part 2



Materials

- Wood (American Wood Fibers)
  - Hardwood maple, 425 microns (40 mesh size)
- Maleated polyolefins (Eastman Chemical Co.)
  - PP-based (MAPP or G-3003 and G-3015)
- Zinc acetate catalyst (Baker Analytical Reagents)
- Batch makeup
  - 79:20:1 weight ratio wood:binding agent:catalyst

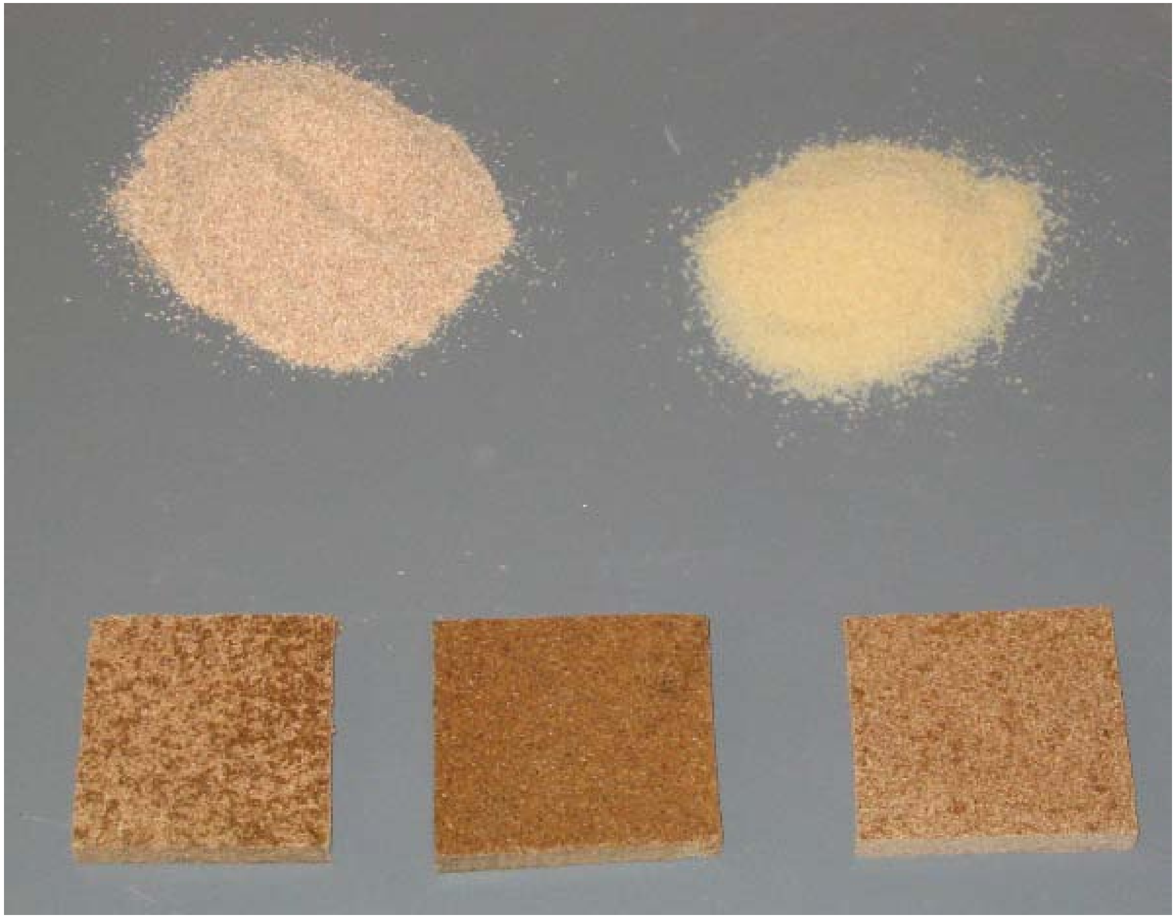
Panel Manufacture

Dry blending at
room temperature
for 10 min.

Reactive extrusion
(160°C, 60 rpm)

Hot press
(193°C, 7 min, 8 Mpa)

Raw Materials and Panel Samples



Property Evaluation

- Density
- Mechanical property tests ASTM D1037.
  - MOR, MOE
  - Internal bond (IB) strength
  - Screw holding capacity
- Property values compared with standard ANSI A208.1 (Particleboard).
- A two-sample t-test with $\alpha = 0.05$ level of significance.

Bending Properties

Particleboard of medium density (640-800 kg/m³)	ANSI Grades				Experimental Values	Average Density (kg/m³)
	M-1	M-S	M-2	M-3		
MOR (MPa)	11.0	12.5	14.5	16.5	23.00 ± 4.7	775 ± 8
MOE (MPa)	1725	1900	2250	2750	2875 ± 347	

From Standard ANSI A208.1-1999 Particleboard

IB Strength and Screw Holding Capacity

Panel Types	Properties	
	IB Stregth(MPa))	**Screw holding (N)**
Medium density grades (Standard ANSI A208.1)	0.40 – 0.55	900 - 1100
MAPP-panel	1.50	1580

Conclusions

- Panels were formed from modified wood particles produced through reactive extrusion;
- Composites contained no formaldehyde-based adhesives;
- Mechanical properties meet or exceed standard requirements.

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References

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2. K. Carlborn and L.M. Matuana, "Modeling and Optimization of Formaldehyde-Free Wood-Based Composites Using a Box-Behnken Design," *Polymer Composites*, **27** (5): 497-503 (2006).

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5. K. Carlborn and L.M. Matuana, "Composite Materials Manufactured From Wood Particles Modified Through a Reactive Extrusion Process", *Polymer Composites*, **26** (4): 534-541 (2005).