

# Design of Wood Thermoplastic Composites for Resistance to Decay and Moisture

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SWST/FPS - Newport Beach, CA - June 25, 2006



## Co-Researchers

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- Bessie Woodward  
*US Forest Products Laboratory*
- Funding from Office for Naval Research

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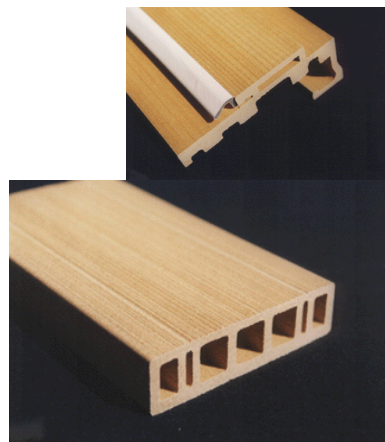
## Publications

- Pendleton, D.E., T.A. Hoffard, T. Adcock, B. Woodward, and M.P. Wolcott. 2002. Durability of an Extruded Hdpe/Wood Composite. **Forest Products Journal**. 52[6]:21-27.
- Schirp, A. and M.P. Wolcott. 2005. Influence of fungal decay and moisture absorption on mechanical properties of extruded wood-plastic composites. **Wood and Fiber Science**. 37[4]:643-652.
- Schirp, A. and M.P. Wolcott. 2006. Fungal degradation of wood-plastic composites and evaluation using dynamic mechanical analysis. **Journal of Applied Polymer Science**. 99[6]:3138-3146.



## Thermoplastic Composites

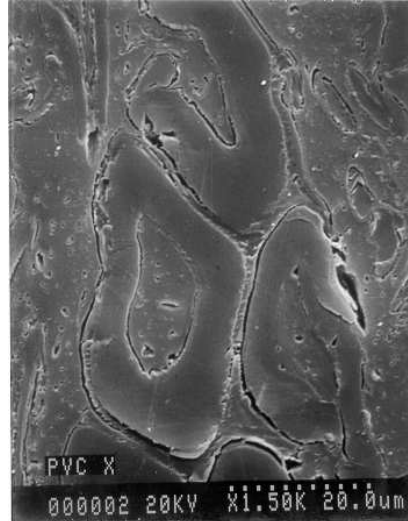
- Sold on Improved Durability to Wood  
*Moisture and Dimensional*  
*Fungal*  
*UV*
- Decking Market Share  
*1997 - 2%*  
*2004 - ~20%*
- Total Retail Value  
*\$1 billion USD*





## Polymer-Wood Alloy

- Wood Dispersion  
*Reinforcement  
Imparts Properties*
- Polymer Matrix  
*Continuous Phase  
Impregnate Wood  
Structure*
- Coupling Agents  
*Dispersion  
Wetting  
Interaction*



## Objectives of Research

- Mixtures Design of Experiment  
*Assess Component Contribution to Decay  
Range for Formulation Design  
Wood, HDPE, Talc, Zinc Borate*
- Examine Possible Mechanisms for Attack  
*Various Exposures  
Several Response Variables  
Weight Loss, Moisture Content  
Mechanical Properties, Dynamic Mechanical Analysis*



## Material Manufacture

- Dry Blending
- Extrusion  
*CM 55 Conical Twin Screw  
Counter-Rotating*
- Coupon Test Plaques  
*1 x 6 inch  
Planed Surfaces*
- Characterization  
*Mechanical  
Moisture  
Bio-Degradation*



## Formulation

### Multi-Components

- Wood Flour  
*Flour - 45-70%*
- Thermoplastic  
*HDPE  
24-45%*
- Talc  
*0-8%*
- Zinc Borate  
*0-4%*
- Additives  
*Thermosets (PF, MDI)  
Lubricants (Zinc Sterate, EBS)  
1-3% each*

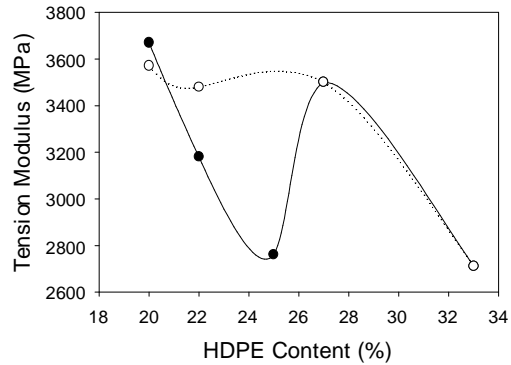




## Experimental Design

- Components  
*Sum to 1.0*
- Increase HDPE  
*What to remove?*
- Response  
*Entire Formulation*
- Full Design  
*Too Large*

$$\sum_{i=1}^n x_i = 1$$



## Simplex Design

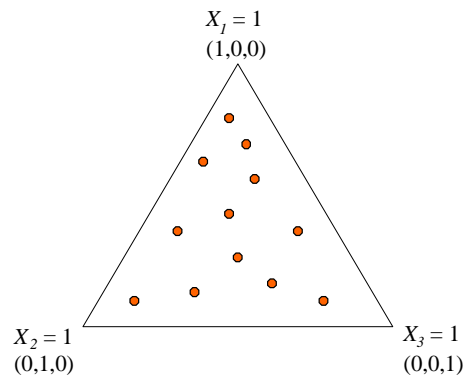
- Response Surface

$$\eta = \sum_{i=1}^q \beta_i x_i + \sum_{i < j} \sum_{j=1}^q \beta_{ij} x_i x_j$$

- Multi-Component Mixtures

$$\sum_{i=1}^n x_i = 1$$

- Simplex Region  
*Design Space*





# Formulations

No.	COMPONENTS				
	Wood	HDPE	ZB	Talc	Additives
1	45	39	10	0	6
2	45	39	10	0	6
3	49	45	0	0	6
4	49	45	0	0	6
5	53	33	8	0	6
6	51	36	7	0	6
7	70	24	0	0	6
8	58	32	4	0	6
9	58	32	4	0	6
10	49	41	4	0	6
11	47	45	2	0	6
12	64	28	2	0	6
13	53	33	0	8	6
14	49	41	0	4	6
15	65	29	0	0	6

**Wood**  
40 mesh  
Maple

**HDPE**  
0.1 MFI

**Zinc Borate**  
Firebreak ZB

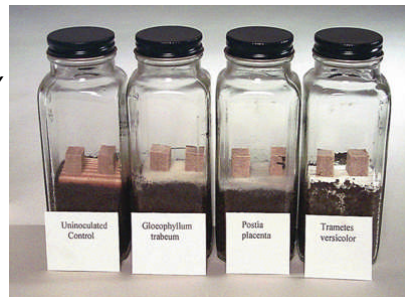
**Talc**  
Suzorite  
2661

**Additives**  
2-Zn St  
1-EBS Wax  
3-PF&MDI



# Accelerated Decay Testing

- ASTM D 1413  
*Test for Wood Preservatives by Laboratory Soil-Block Cultures (AWPA-E10)*
- Feeder Stip  
*Southern Pine*
- Fungi  
*M 617- Gloeophyllum trabeum*  
*M 698- Poria placenta*  
Brown Rot  
*M 697- Trametes versicolor*  
White Rot





## Average Weight Loss (%)

No.	Ave. Weight Loss (%)			
	M617	M697	M698	Controls
1	-3.00 (0.41)	-2.79 (0.47)	-2.53 (0.59)	-3.34 (0.27)
2	-2.44 (0.28)	-2.67 (0.23)	-2.86 (0.23)	-2.48 (0.31)
3	0.23 (0.68)	-1.23 (0.46)	0.58 (0.38)	-2.48 (1.09)
4	-0.24 (0.58)	-0.95 (0.43)	0.32 (0.39)	-2.79 (0.18)
5	-0.87 (0.37)	-0.93 (0.41)	-0.89 (0.26)	-0.99 (0.42)
6	-0.07 (1.62)	-1.10 (0.37)	-0.96 (0.43)	-1.40 (0.45)
7	<b>4.90 (0.84)</b>	<b>4.24 (1.48)</b>	<b>8.47 (0.80)</b>	<b>-1.56 (0.25)</b>
8	-0.44 (0.39)	-0.80 (0.18)	-0.66 (0.24)	-1.24 (0.18)
9	-0.36 (0.18)	-0.30 (0.37)	-0.58 (0.21)	-1.16 (0.23)
10	-1.80 (0.02)	-1.66 (0.24)	-1.50 (0.23)	-2.17 (0.45)
11	-1.34 (0.18)	-0.97 (0.29)	-0.78 (0.22)	-1.11 (1.77)
12	-1.20 (0.40)	0.10 (1.54)	-0.94 (0.34)	-1.23 (0.32)
13	<b>0.85 (1.42)</b>	<b>2.57 (3.50)</b>	<b>4.30 (1.97)</b>	<b>-1.59 (0.29)</b>
14	-0.22 (0.82)	-1.53 (0.57)	0.01 (0.41)	-2.63 (0.35)
15	<b>1.36 (0.80)</b>	<b>0.29 (0.93)</b>	<b>3.28 (0.39)</b>	<b>-1.64 (0.25)</b>



## Predictive Equations

- M617- *G. trabeum*  

$$\eta = 0.07w - 0.10p - 0.18z + 0.20t$$
- M697- *T. versicolor*  

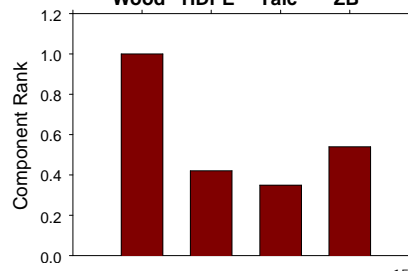
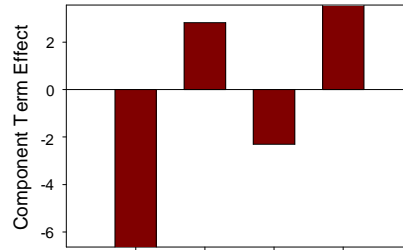
$$\eta = 0.10w - 0.12p - 0.36z + 0.25t$$
- M698- *P. placenta*  

$$\eta = 0.06w - 0.08p - 0.25z + 0.01t$$
- where:  $\eta = \text{weight loss } (-\%)$   
 $w = \text{wood } (\%)$   
 $p = \text{HDPE } (\%)$   
 $z = \text{zinc borate } (\%)$   
 $t = \text{talc } (\%)$



## Component Contribution

- Component Ranks
  1. Wood
  2. Zinc Borate
  3. HDPE
  4. Talc
- Contribute to Decay  
*Wood, Talc*
- Resist Decay  
*HDPE, Zinc Borate*
- M697- *T. versicolor*

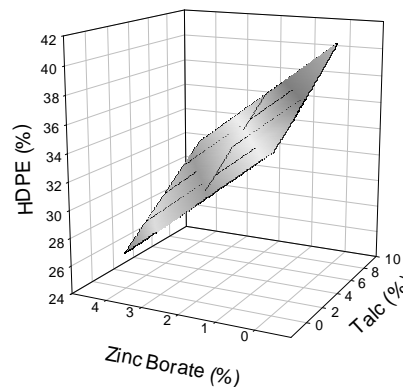
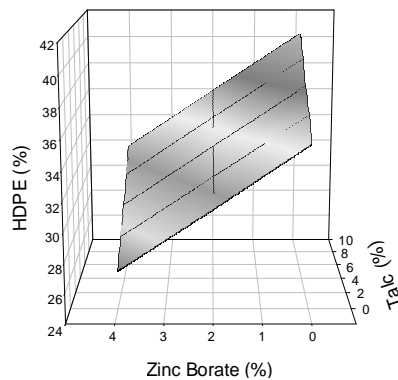


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## Decay Resistant Formulation



2% Mass Loss- M697- *T. versicolor*

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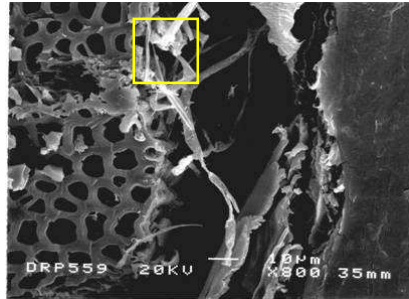




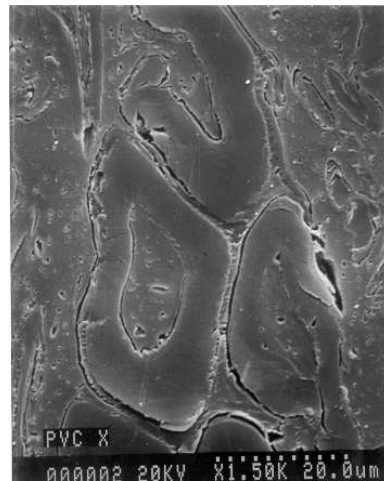
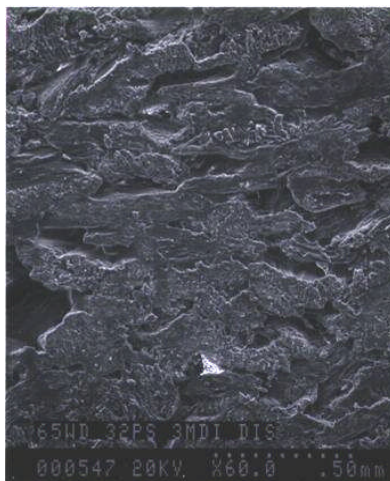
## Decay Process

### Wood-Plastic Decay

- Exterior Erosion  
*Surface Wood*
- Fungi Propagate  
*Wood-Plastic Interface*  
*Interfacial Gaps*
- Moisture Paths



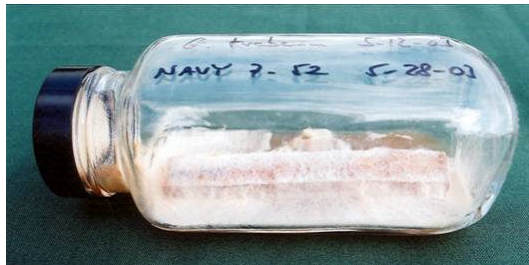
## Wood-Plastic Structure





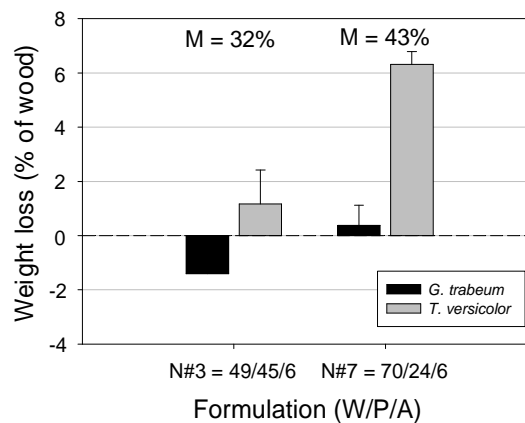
## Addressing Mechanisms

- Selected Formulations (W/P/A)
  - N#3 = 49/45/6*
  - N#7 = 70/24/6*
- Treatments
  - Control*
  - Control (Incubated)*
  - G. tradaeum*
  - T. versicolor*
- Response
  - Moisture*
  - Weight Loss*
  - DMA*
  - Flexure*



## Weight and Moisture

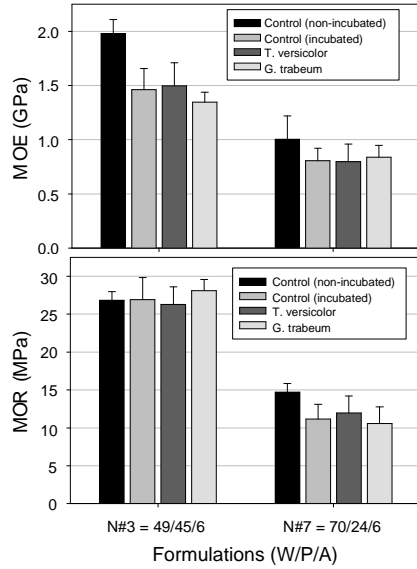
- *f(w)*
  - Weight Loss*
  - Moisture Content*
- Moisture Content
  - Incubated Controls*
  - Sterile Agar*
  - No Fungi*
- Moisture Content
  - > 30%*
  - Support Decay*





# Mechanical Properties

- Most Responsive  
*Loss in MOE*  
*Moisture NOT Decay*
- Moisture  
*Largest Loss*
- Decay  
*During Accelerated Test*  
*No Significant Influence*  
*MOE or MOR*



# DMA Properties

- Dynamic Properties

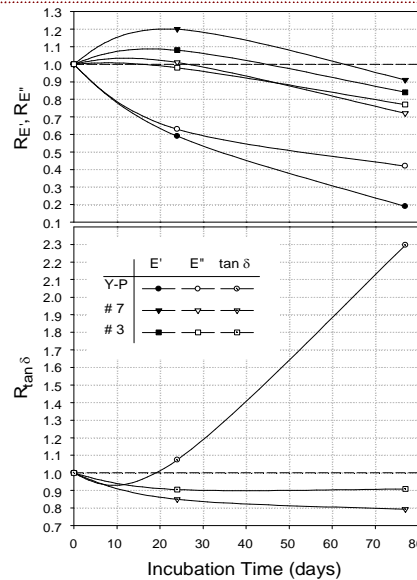
$$E^* = \frac{\sigma_o}{\epsilon_o} = \sqrt{E'^2 + E''^2}$$

$$\tan \delta = \frac{E''}{E'}$$

- Property Ratio

*Decay*  
*Inoculated Control*

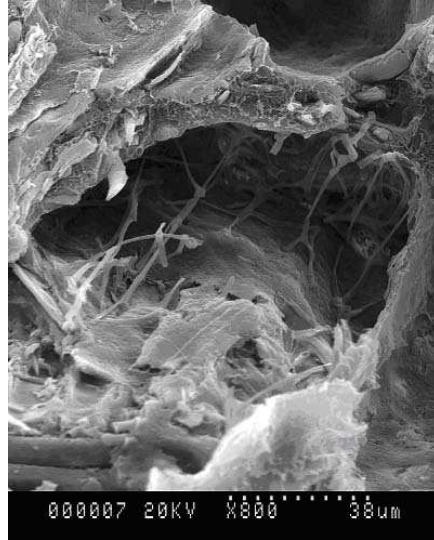
$$R_x = \frac{X_{decay}}{X_{control}}$$





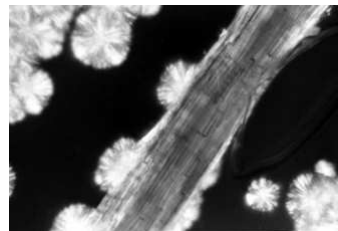
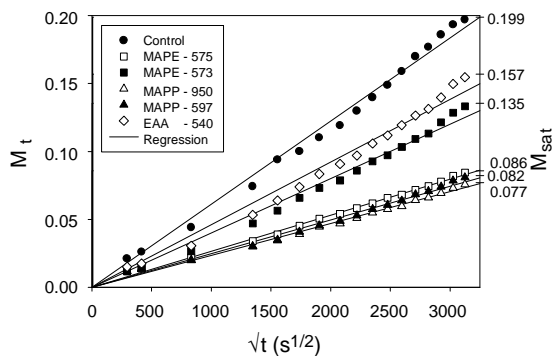
## Interface Routes

- Wood-Plastic Interface  
*Gaps Form*  
*Route for Moisture*  
*Route for Fungi*
- Barrier Layer  
*High Plastic Content*  
*Form Complete Barrier*  
*Maintain Integrity*

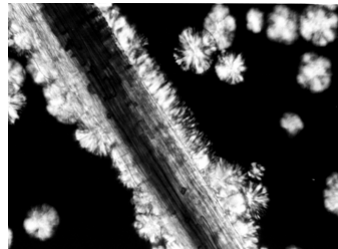


## Moisture and Interphase

- Coupling Agents  
*Reduce or Retard Moisture*
- Wood Moisture Contents  
*33% (Control) to ~13% MAPP/PE*



Unmodified



MAPP Modified

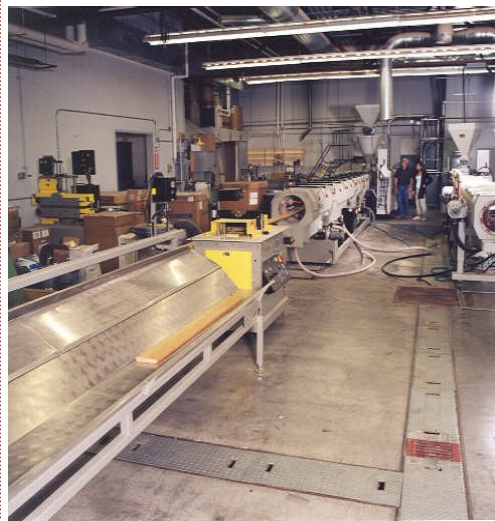


## Conclusions

- Decay Resistant Thermoplastic Wood Composites Can Be Produced
- Decay Occurs for Surface Erosion
- Can Penetrate if Barrier Layer is Degraded
  
- Accelerated Methods for Wood May Not Be Adequate for WPC's
- Use of Moisture as Probe is Unknown
- Role of Barrier Layer Effects Should be Considered Past WPC's



## QUESTIONS



### Electronic Contact Info

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