FUNCTIONALLY GRADED COMPOSITES FOR IMPROVED ARMOR

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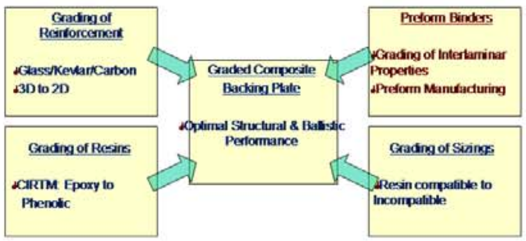
Grading of Composite Backing Plate



Acknowledgements

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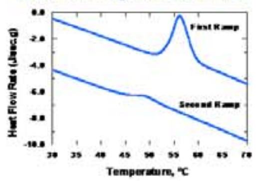
Binder Characterization

Binders: Powdered polymers that melt onto and possibly react with glass fabrics upon application of heat and pressure to form a net-shape preform

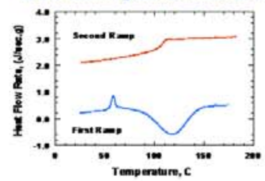
Types of Binders

- Low-melting thermoplastic polyester
- Reactive Epoxy (heat activated)

DSC thermogram of ATLAC



DSC thermogram of PRETEX



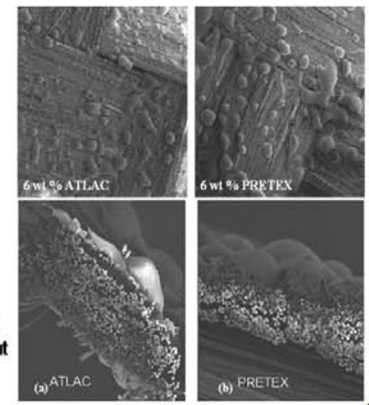
Preform Analysis

Correlate Processing Parameters (Temperature, Pressure) to binder coverage, spread, and tow impregnation

Binder Coverage and Tow

Impregnation Influence

- Interply Strength
- Preform Springback
- Shape Retention
- Permeability
- Fiber Wet-out



Interply Adhesion

T-peel Test

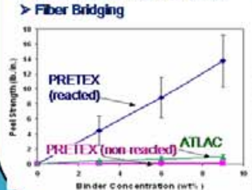
ASTM Standard D 1876-95

Purpose of Experiment

- Evaluate Structural Integrity of Preforms
- Type of adhesion: mechanical vs. chemical

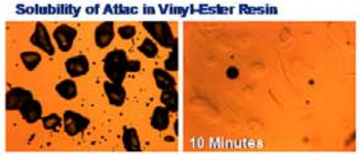
T-peel Test Results

- Reactive binder provides much higher interply strength (15X)
- Additional Chemical Adhesion
- Fiber Bridging



Binder-Resin Interactions

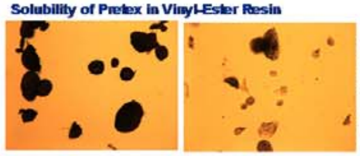
Solubility of Atlac in Vinyl-Ester Resin



Soluble Binders

- Spring-back of Preform
- Reaction Kinetics
- Viscosity/Permeability

Solubility of Pretex in Vinyl-Ester Resin



Insoluble Binders

- Maintain Preform Compaction
- No Reaction Kinetics
- Permeability

- Higher concentrations of dissolved binder result in significant increases in:
  - Resin Gel Time
  - Resin Viscosity

Binder-Resin Interactions

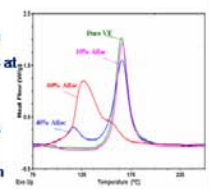
Binder Effects Resin Cure Kinetics

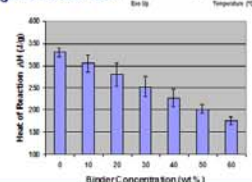
DSC Experiment

- Fully Dissolved binder in resin
- Heat Ramp from 35° to 300°C at 10°C per min.

Significance of Experiment

- Determine if binder influences reaction kinetics
- Provide insight on binder/resin reactivity, dH



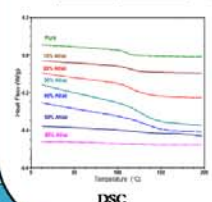


Binder-Resin Interactions

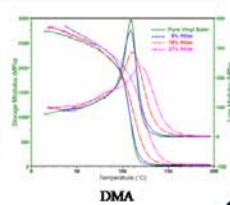
- Binder Influence on Resin Tg
  - Dissolved Binder Increases Resin Tg at higher Concentrations

Atlac (wt%)	Tg
0	112.6
10	114.1
20	115
30	127.2
40	137.3

Atlac (wt%)	Tg (loss)	Tg (storage)
0	109.8	110.2
6	110.2	109.7
18	111.9	112.5
27	119.2	121.1



DSC



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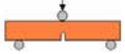
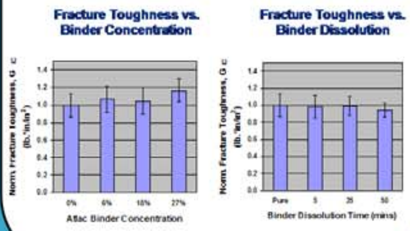
Binder-Resin Interactions

- Binder Influence on Resin Fracture Toughness

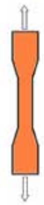


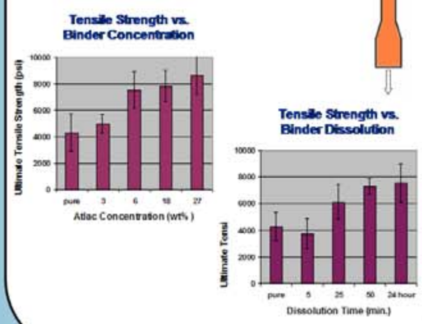
ASTM D 5045: 3-Point Bend of SENB
- Fully Dissolved, different Atlac Concentrations
- 6 wt% Atlac binder, different dissolution times



Binder Influence on Resin Tensile Properties

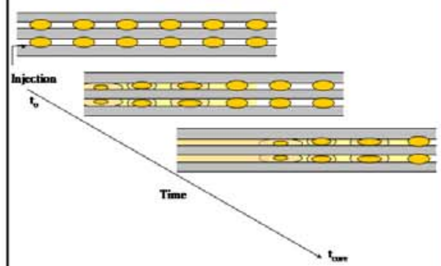
ASTM D 638: Tensile Test
- Fully Dissolved, different Atlac Concentrations
- 6 wt% Atlac binder, different dissolution times





Binder-Resin Interactions

Binder Dissolution



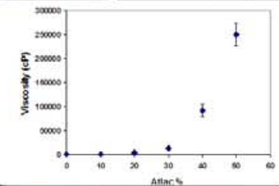
- Concentration gradients may be formed
- Extent of dissolution affects processing of preform
  - gel times, viscosity, permeability
- Affects Mechanical Properties
  - tensile, toughness, Tg

Binder-Resin Interactions

Monitoring Binder Dissolution- Viscosity Approach

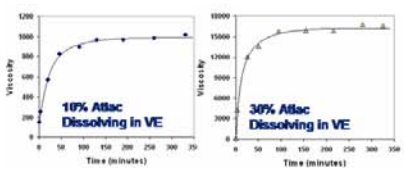
Vinylester/ soluble Atlac Binder
- Viscosity is drastically affected by amount of dissolved binder
- Monitor viscosity to predict dissolution

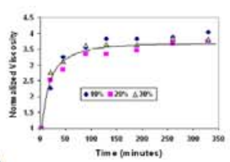
Binder Concentration (wt%)	Average Viscosity (centipoise)
Pure Resin	130 +/-18
10	719 +/-182
20	2,430 +/-448
30	13,148 +/-2,619
40	91,367 +/-13,587
50	250,300 +/-24,039



Binder-Resin Interactions

Monitoring Binder Dissolution- Viscosity Approach





Significance of Experiment
- Estimate time frame for complete dissolution
- Provide input for processing parameters
  - Infusion times
  - Gel times

Significant Mechanisms

Binder/Fiber Interaction
- Mechanical/Chemical Adhesion

Binder/Resin Interaction
- Reaction/Crosslinking
- Dissolution Kinetics

Composite Laminate Performance
- Ballistic Performance
- Damage Tolerance
- Interlaminar Properties

Environmental Issues
- Preform Storage
- TEXT

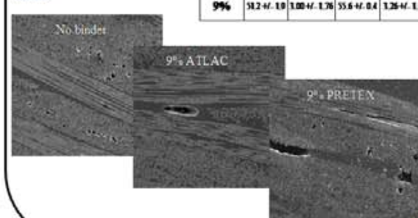
Processing Parameters
- Preform Permeability
- Gel/Cure Times

Composite Performance

- Void Content

Effect of Binder on Void Formation
- Introduction of binder resulted in larger voids concentrated in interlaminar regions
- Laminates containing resin insoluble binder, PRETEX, contained highest degree of voids

Binder Loading	ATLAC 363E		PRETEX 110	
	V_f%	V_v%	V_f%	V_v%
No binder	47.5 +/- 0.5	1.78 +/- 0.21	47.5 +/- 0.5	1.78 +/- 0.21
3%	48.0 +/- 0.6	1.63 +/- 0.28	49.4 +/- 2.4	2.11 +/- 0.24
6%	47.9 +/- 0.9	1.99 +/- 0.57	53.7 +/- 1.6	4.64 +/- 1.71
9%	51.2 +/- 1.0	3.00 +/- 1.76	55.6 +/- 0.4	3.26 +/- 1.03



Conclusions

- Binder Evaluation
  - PRETEX Reactive, Tow Impregnation Limited for both binders
- Preform Evaluation
  - Peel Test: High Interply Adhesion obtained with reactive binder, increases with binder loading
- Binder – Resin Interaction
  - ATLAC: soluble in VE, increases viscosity and delays gel times of resin, reacts with resin, increases Tg and tensile properties of resin, no apparent affect on toughness
  - PRETEX: Not Soluble in VE once fully crosslinked.
- Composite Performance
  - Both binders introduced large interlaminar voids (Insoluble PRETEX introduced most voids)
  - Interlaminar Shear Strength decreases as binder loadings increase
  - Interlaminar Fracture Toughness decreased w/ ATLAC, but increased w/ PRETEX as binder loadings were increased
- Preform binders show promise in being able to tailor interlaminar properties of composite laminates for the development of functionally graded materials
  - Type of binder: reactive with sizing/resin, resin soluble
  - Concentration of Binder
  - Processing: Processing of Preform, Processing of Composite