IN SITU FORMATION OF BARRIER LAYER FOR CIRTM PROCESSING

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OBJECTIVE AND MOTIVATION

- Develop an impermeable separation layer using thermoplastic powder binder
- Conventionally done using thermoplastic film
- Binder or Tackifier - a material that bonds adjacent plies of reinforcement fabric
- Binder sprinkled and melted on fabric by heat and pressure
- Advantages:
  - Complex preforms easily done
  - Promotes mechanical interlocking for load transfer
  - Easy modification of properties of interlaminar layer
  - Cost effective

CO-INJECTION RESIN TRANSFER MOLDING

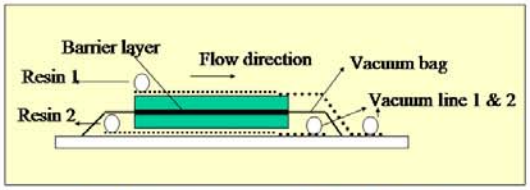
- Single step process for multi-functional hybrid laminates

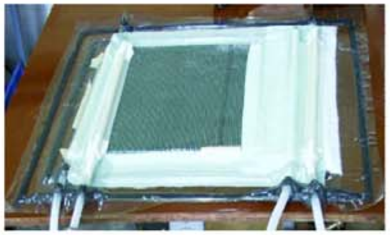


- CIRTM - simultaneous injection of two or more resins into a single cavity mold, which contains a stationary fiber preform
- Successfully co-injected resin combinations: Epoxy/VE, Epoxy/Phenolic, VE/Phenolic, Phenolic/Urethane
- Advantages:
  - Considerable cost savings
  - Good mechanical properties due to co-cure
- Disadvantages:
  - Resins must have compatible cure cycles
  - Requires a barrier layer to separate flows of the 2 resins

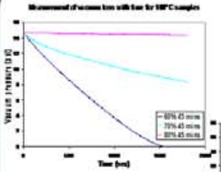
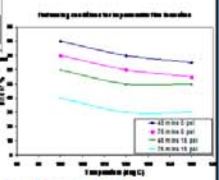
TYPICAL CIRTM SET-UP

- Schematic of experimental setup for co-injection:





PREFORMING CONDITIONS

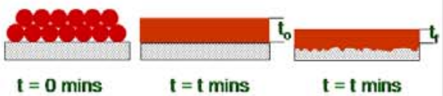



- Increase in preforming temperature, preforming time, or preforming pressure results in better seal at the boundary where flow fronts of two particles meet.

MECHANISMS

- Possible mechanisms of binder spread:

- 29% binder particles give full coverage per unit area of fabric. 30 – 80 % binder:

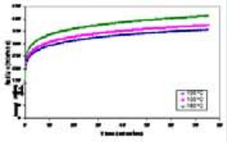


- Assumption: Spreading is a two-step process
  - On the surface to form a film of thickness t_o
  - Into the surface to give final thickness t_f

FILM FORMATION: STEP 1

- Simple - Absence of transverse flow, surface roughness, anisotropic drop spreading
- Radius of viscous drop:

$$r(t) = \zeta\left[V^{3\delta}\left(\frac{\gamma(T)}{3\mu(T)}\right)^{\delta}\right]t^{\delta}$$



V = Volume of drop,
γ(T) = Temp. dependent surface tension,
μ(T) = Temp dependent zero shear viscosity
$\delta = 0.1$, $\zeta = 0.94451$

- Surface tension: Micro-Wilhelmy Technique
- Viscosity: Rheometry

[1] J. A. Diez, R. Gratton, L.P. Thomas and B. Marino, *Phys. Fluids*, 6, 24-33 (1994).

IMPREGNATION: STEP 2

- Transverse flow into fabric
  - Capillary pressure – Ahn *et al* [1], Foley M. *et al* [2]
  - Gravity pressure - $\rho g h$
  - External applied vacuum pressure
- Using Darcy's law in Z direction,

$$h = \left(\frac{1}{(1-v_f)}\frac{K_{zz}}{\eta}\Delta P t\right)^{0.5}$$

h = impregnation depth
v_f = fiber volume fraction,
K_{zz} = Permeability in Z direction,
ΔP = Driving pressure gradient,
t = time

- $\Delta P = P_{capillary} + P_{gravity} + P_{applied} - P_{atm}$ $(P_{atm} \sim 0)$
- K_{zz} ➡ Capillary model, Lubrication model

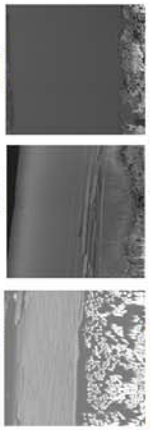
[1] Ahn, K.J., and Seferis, J.C., "Simultaneous Measurements of Permeability and Capillary Pressure of Thermosetting Matrices In Woven Fabric Reinforcements," *Polymer Composites*, 12 (3), 146-152, (1991).
[2] Foley, M.E., and Gillespie, J. W., Jr., "The Effect of Bundle Size on Tow Impregnation during Liquid Molding Processes," SAMPE Conference, May 2001.

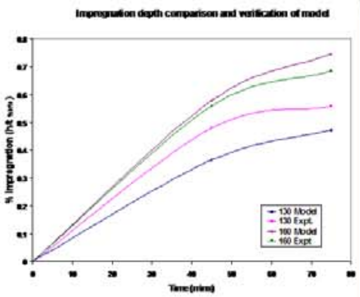
IMPREGNATION DEPTH

100°C
45 mins
0 µm

130°C
45 mins
307 µm

160°C
45 mins
358 µm





Best Experimental and theoretical Fit:
Ahn's capillary pressure
K_{xx} lubrication

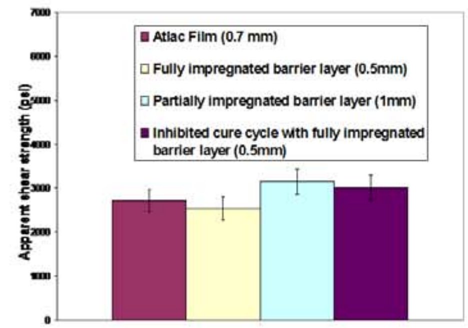
POROUS SUBSTRATE

For 50% impregnation depth		
	No vacuum	15 psi vacuum
Temp.(°C)	Time (mins)	Time (mins)
100	142	17
130	85	10
160	34	4

- Verifies the assumption of two-step film formation at lower temperatures
- Lower temperatures give better control of impregnation
- Using the model, other impregnation depths can be predicted as a function of preforming conditions
- Optimum concentration can be now determined considering
  - Vacuum seal
  - Dissolution

CASE STUDY FOR CO-INJECTION

- Short beam shear test:



- Laminates have shear strength comparable to that obtained using thermoplastic film.

CONCLUSIONS

- The binder concentration required is primarily governed by the vacuum leaks.
- Film formation is a two-step process:
  - Melting and lateral spread of each binder particle to form a film on the surface
  - Impregnation of the film into the surface.
- The preforming time, temperature, and pressure can be optimized to give the required impregnation of binder into fabric
- Co-injected laminates with in situ barrier layers have strengths comparable to conventionally manufactured laminates.

ACKNOWLEDGEMENTS

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