Accelerated Moisture Infusion in Composites

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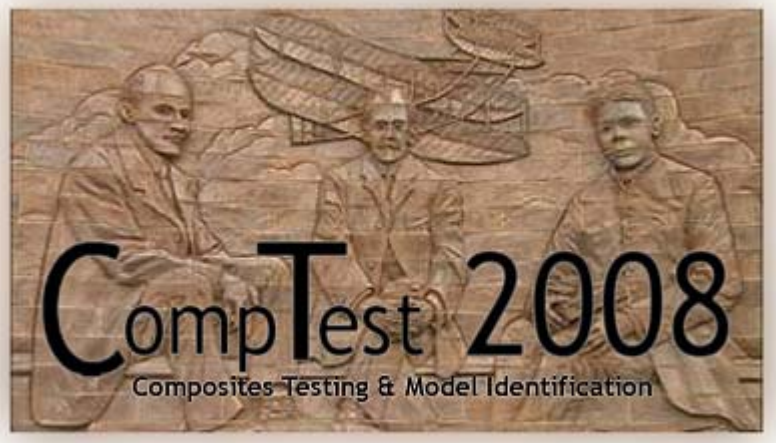

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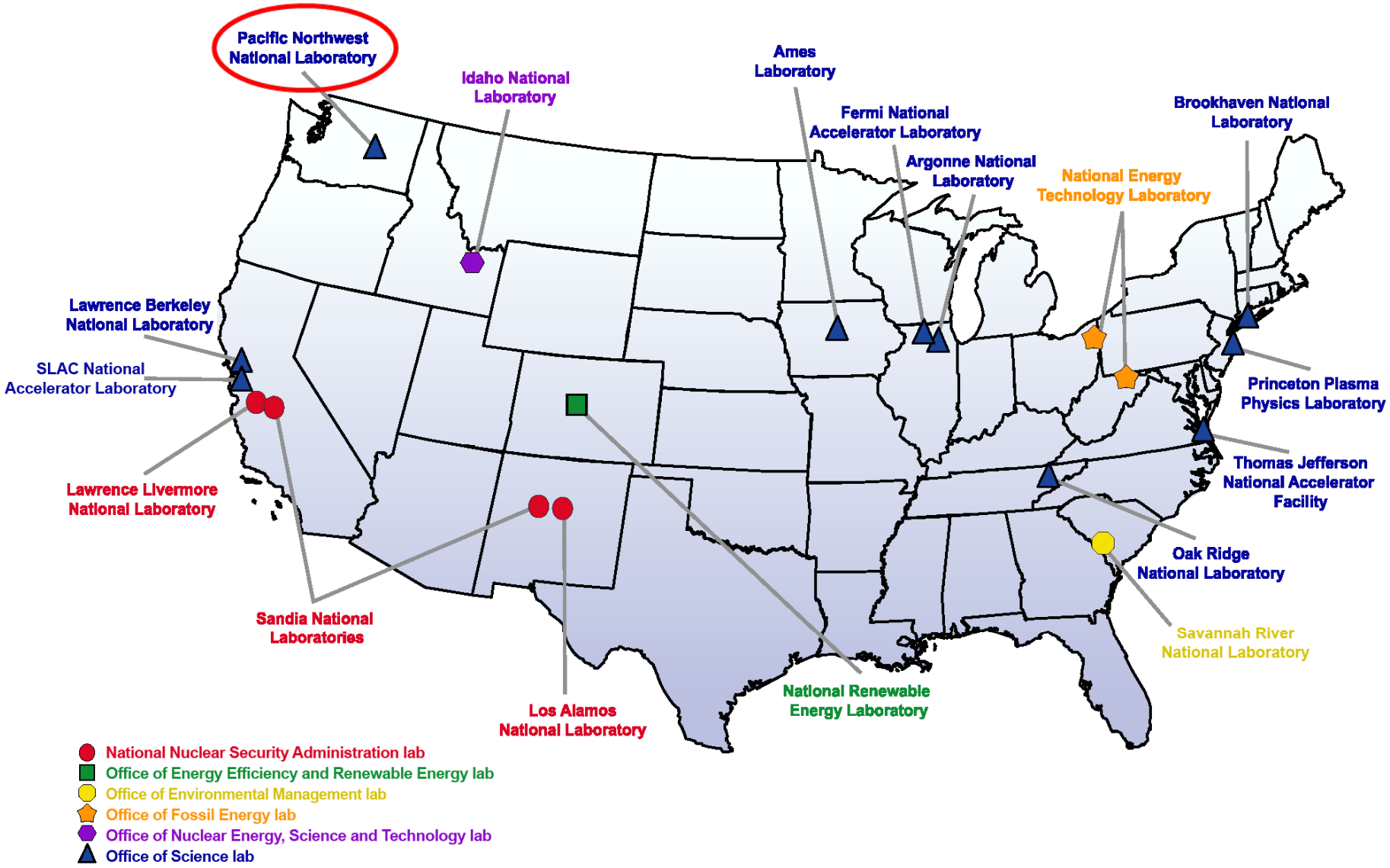
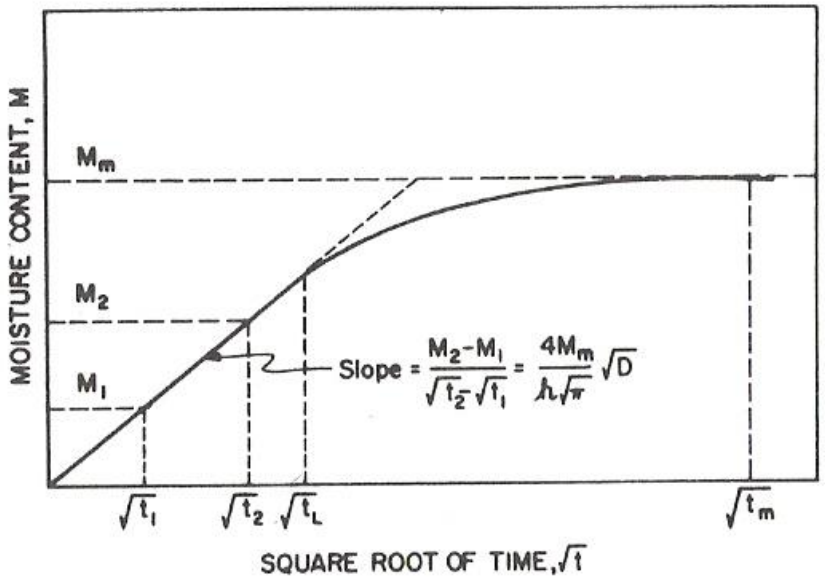


Background



From Shen & Springer, Journal of Composite Materials, 1976. **10**: p. 2-20

- Diffusion Coefficient

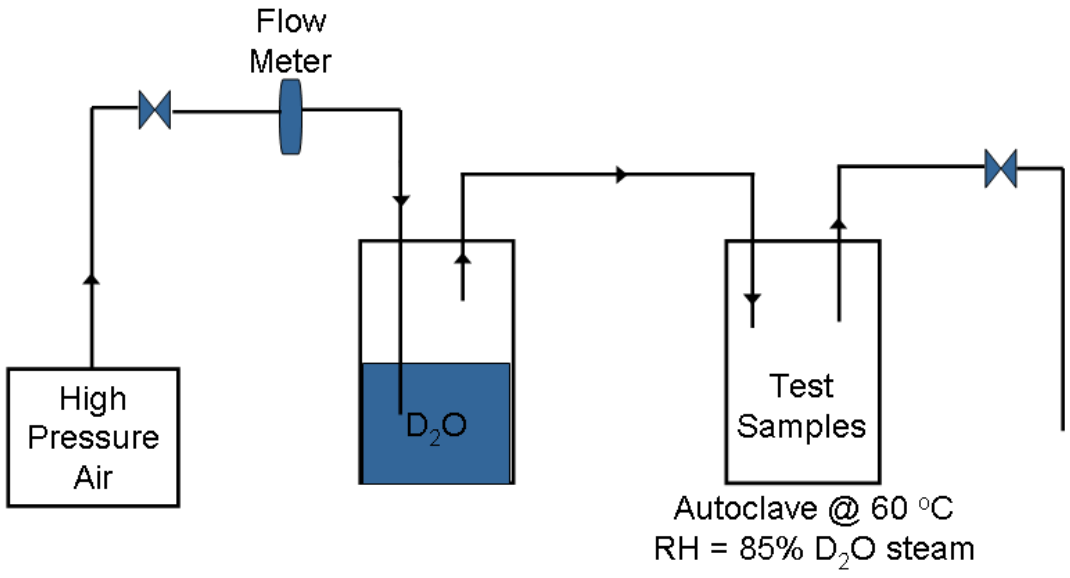
$$D = \pi\left(\frac{h}{4M_m}\right)^2\left(\frac{M_2 - M_1}{\sqrt{t_2} - \sqrt{t_1}}\right)^2$$

- Test the material to saturation i.e. up to $t = t_m$
- $t = t_m$ = Order of several years

- Current Acceleration methods
  - Two-step accelerated conditioning cycles
  - Increase the conditioning/test temperature
- Not very effective

A Novel Accelerated Humidity Test

- High pressure is used to accelerate the moisture ingression.
- In-house built accelerated humidity chamber



Test Parameters

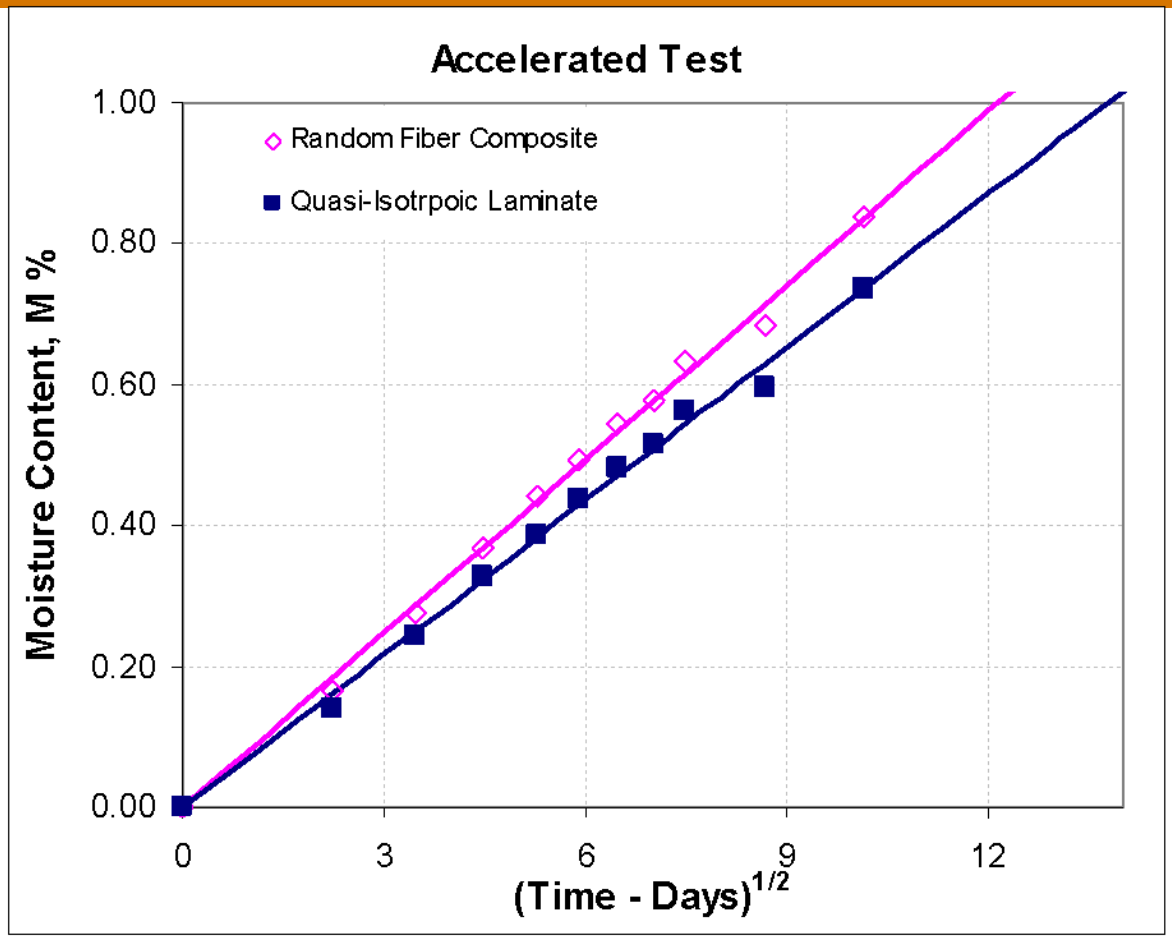
Accelerated

- In-house built accelerated humidity chamber
- 85% RH and 60° C – Similar to standard conditions
- Higher pressures of ~ 65 psi is used to accelerate the moisture ingression.
- Two Materials
  - Quasi-Isotropic Laminate
  - Random Fiber Composite
- Specimen Size
  - 50 x 50 x 4 mm

Standard

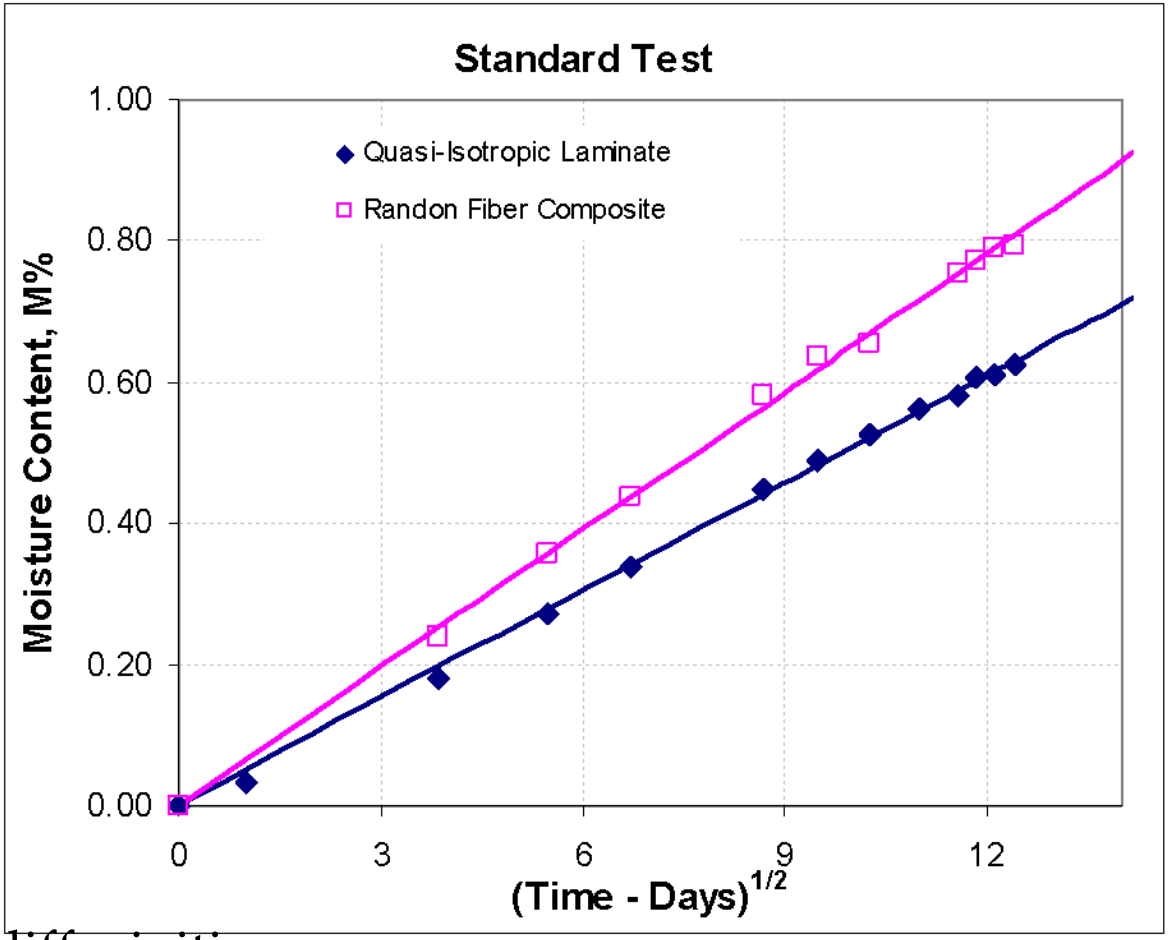
- Tenney Bench top hygro-thermal humidity chamber
- 85% RH and 60° C
- Atmospheric pressure
- Two Materials
  - Quasi-Isotropic Laminate
  - Random Fiber Composite
- Specimen Size
  - 50 x 50 x 4 mm

Accelerated Gravimetric Results



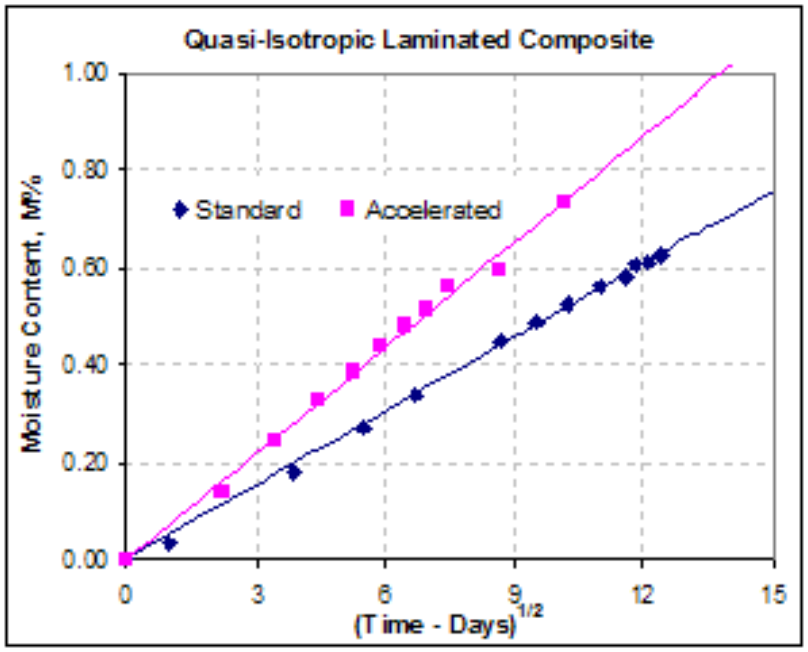
- Estimated diffusivities
  - $D_{\text{Random Fiber}} = 1.4097\text{E-}07\ \text{mm}^2/\text{s}$
  - $D_{\text{Laminate}} = 8.6415\text{E-}08\ \text{mm}^2/\text{s}$

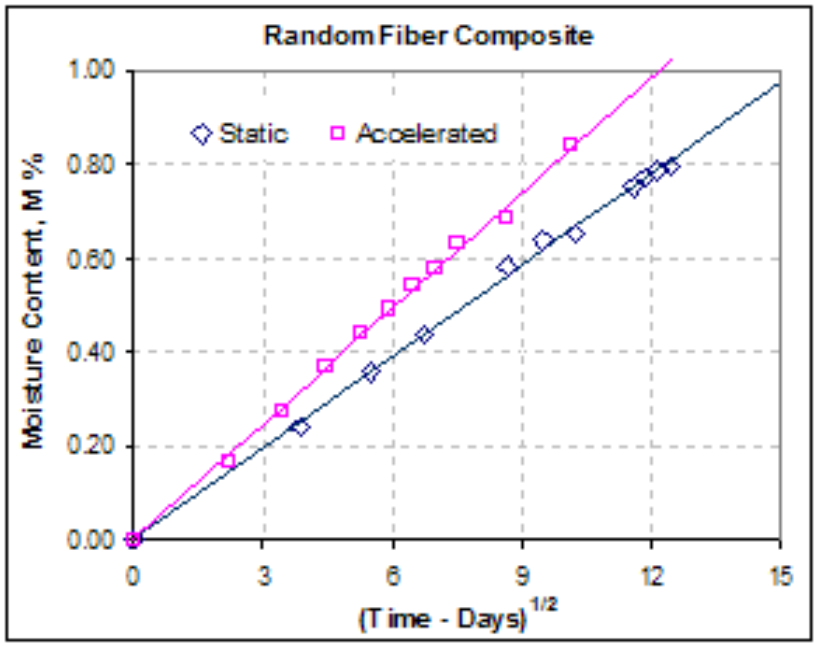
Standard Gravimetric Results



- Estimated diffusivities
  - $D_{\text{Random Fiber}} = 8.0009\text{E-}08\ \text{mm}^2/\text{s}$
  - $D_{\text{Laminate}} = 4.8687\text{E-}08\ \text{mm}^2/\text{s}$

Accelerated vs. Standard - Comparison





Diffusivity mm^2/s	Standard	Accelerated
Quasi-Isotropic Laminate	4.87E-08	8.64E-08
Random Fiber Composite	8.00E-08	1.41E-07

- Diffusivities increased by a factor of ~ **80%**
- Successfully demonstrated that the moisture diffusion can be accelerated using pressure.

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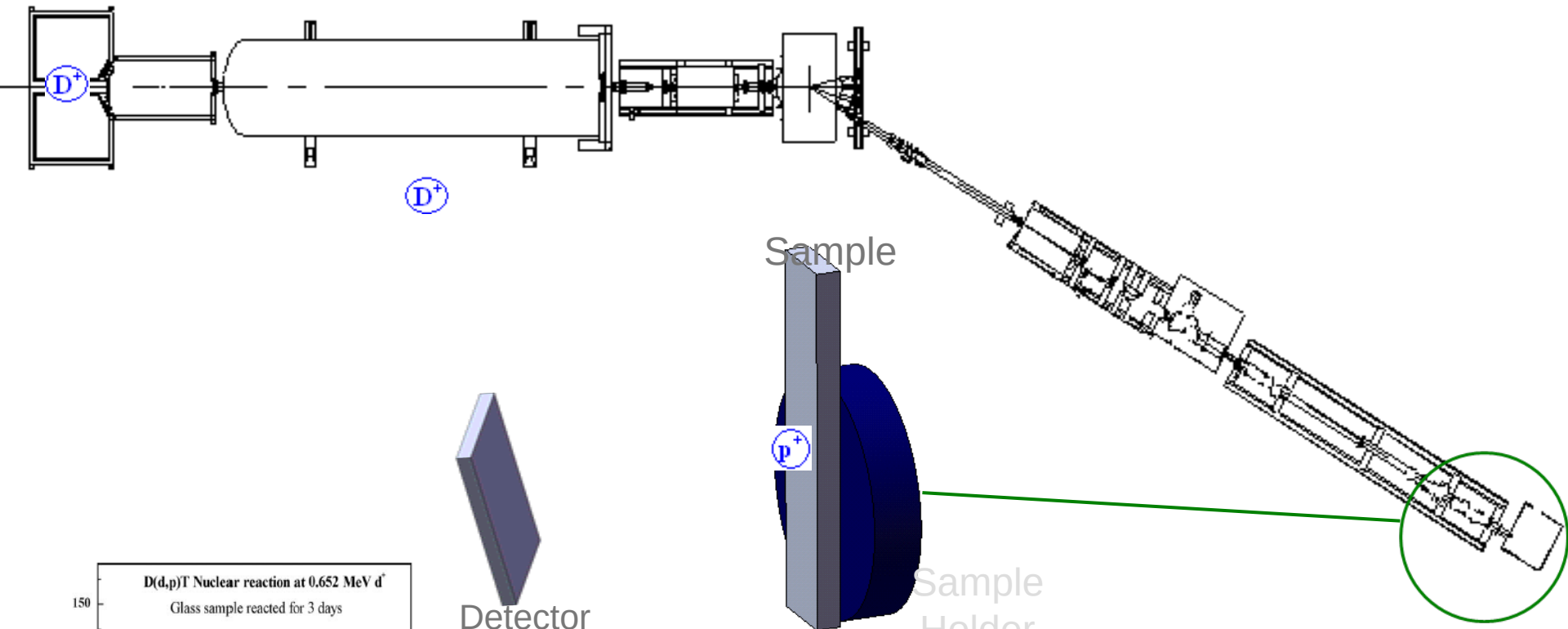
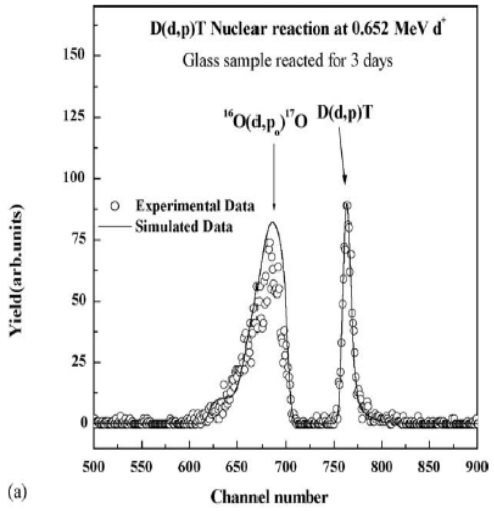
Nuclear Reaction Analysis - Composites

- Nuclear Reaction Analysis – Basic Principle
  - Charged particles (an ion beam) with energy – produced in an accelerator and bombards the sample.
  - Nuclear reactions with low-Z nuclei in the sample are induced by this ion beam.
  - Products of these reactions (typically p, d, t, ^{3}He, α particles, and γ rays) are detected using a spectrum of particle yield versus energy.

- Nuclear Reaction Analysis – Applied to Composites
  - Need to use D_2O instead of H_2O – other wise unable to distinguish the moisture content (H_2O) from the hydrogen and oxygen within the specimen.
  - Uses either **D (d, p)^{1}T** or **D (^{3}He,p)^{4}He** nuclear reaction
  - Proton yield is directly proportional to the deuterium concentration within the reaction volume

Animated View of the Accelerator System





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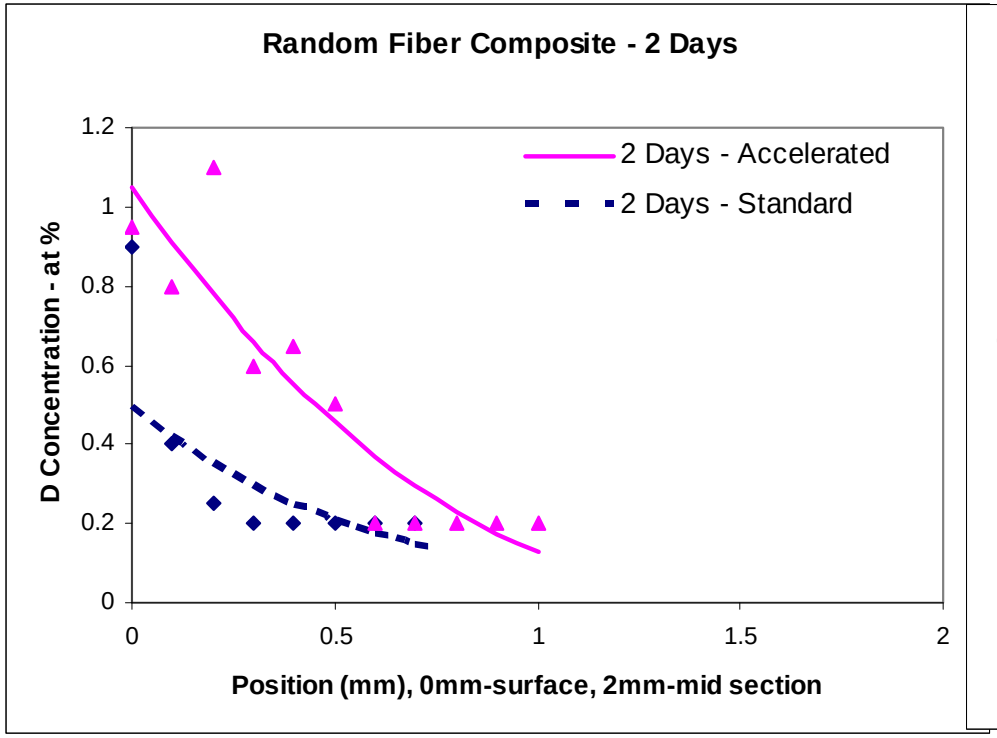
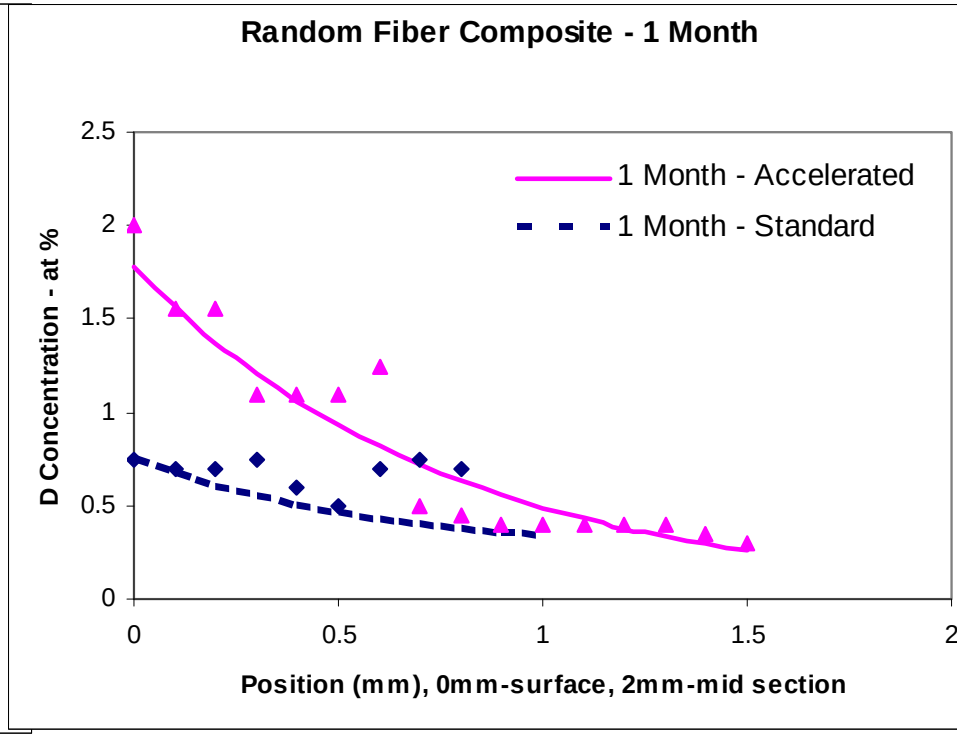
NRA Results – Random Fiber Composite





- Moisture absorption is increasing as a function of time – compares very well with gravimetric analysis

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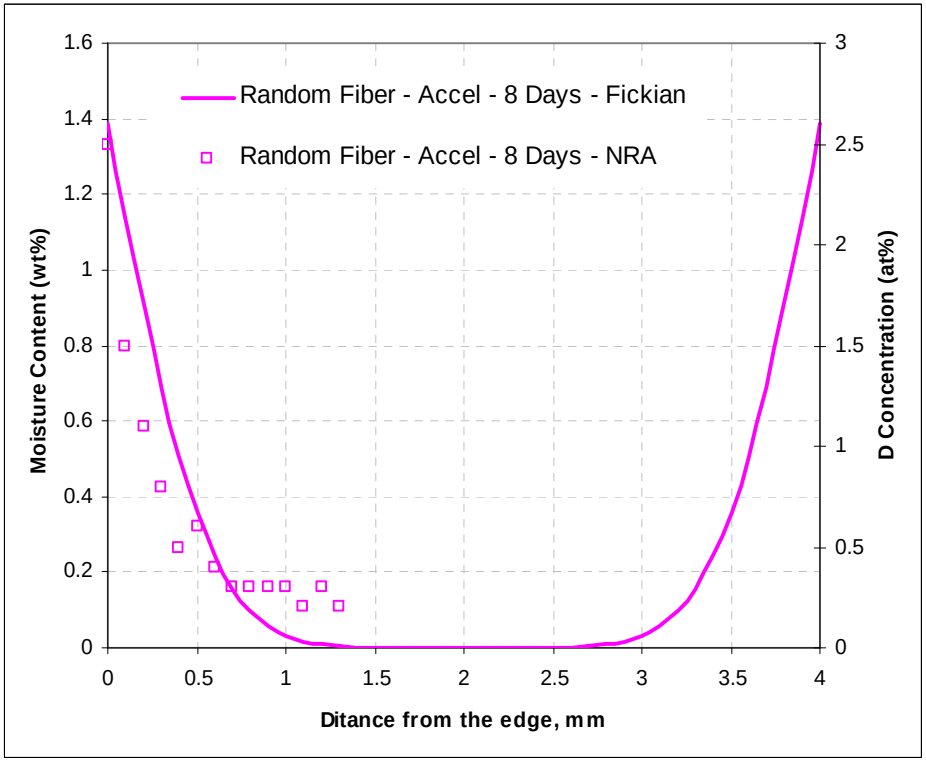
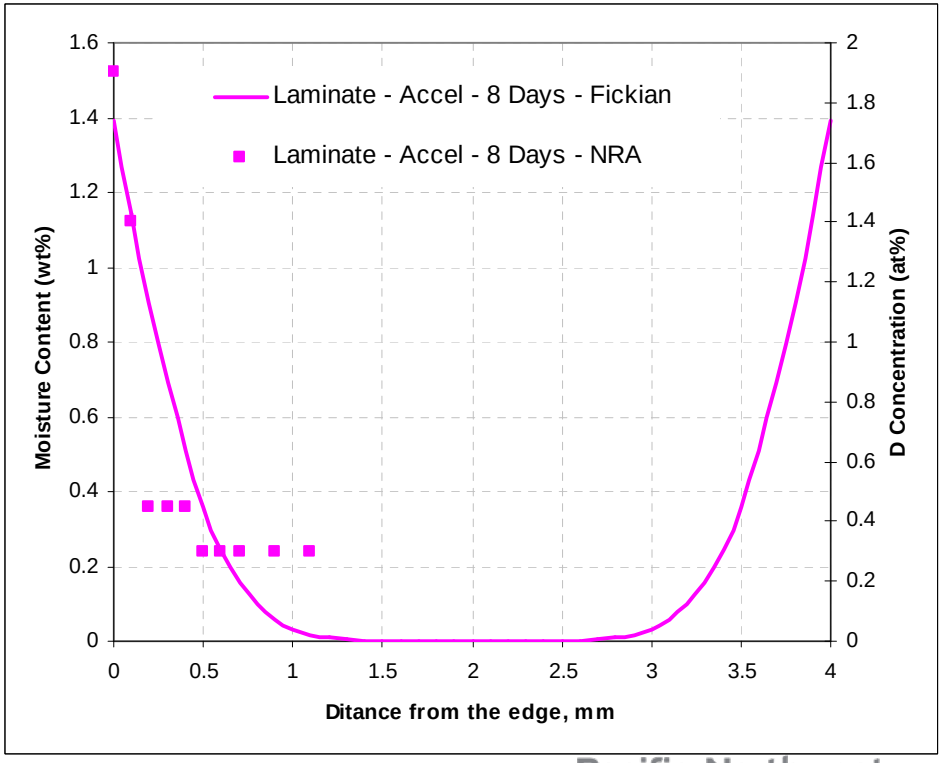
NRA Results – Comparison to Fickian

- Fickian solution

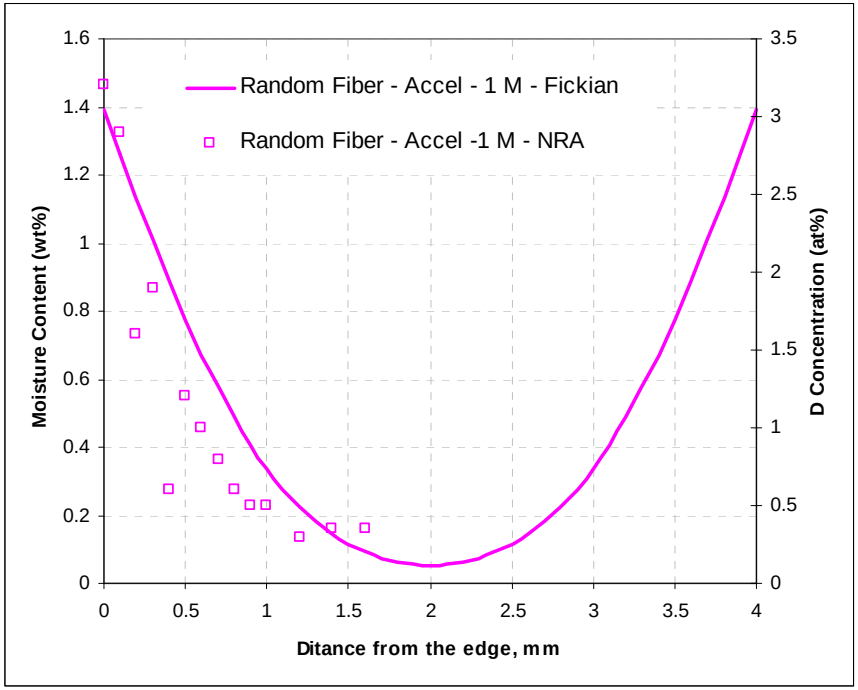
$$C(x,t) := C0 \cdot \left[1 - \frac{4}{\pi} \cdot \sum_{j=0}^{nu} \left[\frac{1}{2 \cdot j + 1} \cdot \sin\left[(2 \cdot j + 1) \cdot \frac{\pi \cdot x}{h} \right] \cdot \exp\left[- \frac{(2 \cdot j + 1)^2 \cdot \pi^2 \cdot D \cdot t}{h^2} \right] \right] \right]$$

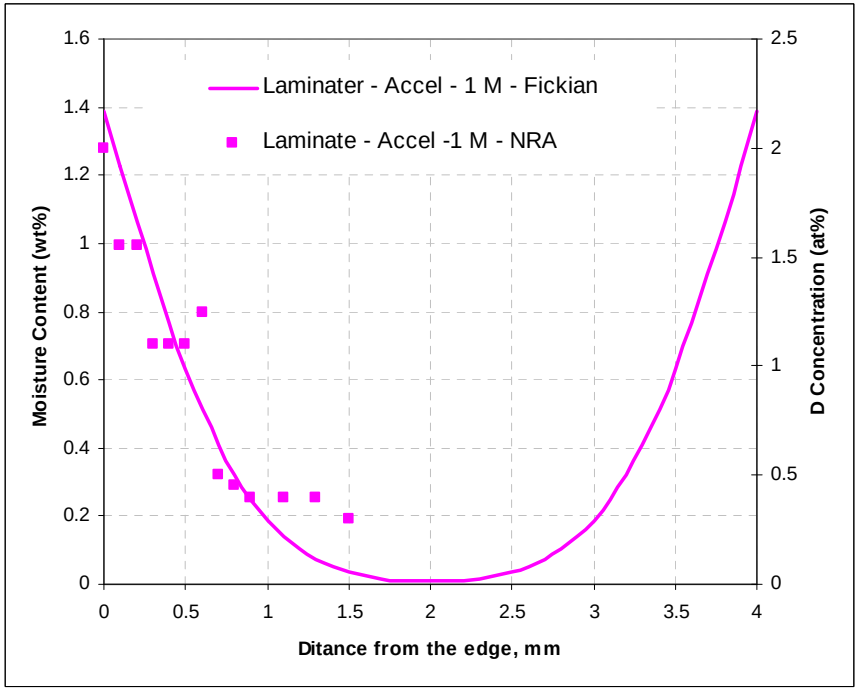
- Compare accelerated NRA curves with Fickian curves





NRA Results – Comparison to Fickian





- The trend of NRA measurements shows similar trends when compared to Fickian absorption curves
- The scatter observed within the NRA measurements is inherent to the composite material system (resin rich vs. fiber rich area)

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Conclusions

- Successfully demonstrated that moisture ingression can be accelerated using pressure
  - Diffusivities increased by a factor of ~**80%**
- Successfully demonstrated that NRA can be used to measure deuterium (moisture) concentration

Time to Saturation, Years	**Static**	**Accelerated**
Quasi-Isotropic Laminate	**7.0**	**3.9**
Random Fiber Composite	**4.2**	**2.4**

  - The above values are based on the diffusivities calculated from the 160 days for static and 103 days for accelerated tests

- Accelerated testing at higher pressures might further decrease the time to saturation

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Acknowledgements

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- Questions? Comments!!

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