Displacement Test Protocol Considerations

Sam L. Samuels
DuPont Photovoltaic Solutions

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Why develop new “creep” tests?

- **Assure safety of installed modules**
  - Collect evidence of existing problems due to displacement at elevated temperature
  - Prevent future failures due to displacement

- **Predict and prevent module failure due to relative displacements of components under load at elevated temperature**
  - Define “Module Failure”
  - Quantify “Load”
  - Define “Elevated Temperature”

- **Provide additional support for lifetime warranty**

The case for MODULE testing/qualification

- **Safety and performance are dependent on module design**
- **Loading conditions are well defined *and meaningful***
  - Temperature exposure conditions
  - Load/geometry
    - Gravity
    - Other
- **Straightforward method development**
  - Mount and load module under severe (TBD) test conditions and measure displacements vs. time
  - Define failure criteria
- **Issue: How to accelerate and be assured that response mechanism(s) are relevant to field performance.**
    - Avoid introduction of new failure mechanisms, e.g.:
      - Melting
      - Flow
    - Continuous exposure vs. intermittent (real-world) exposure can significantly accelerate without changing mechanism

The case against MATERIAL qualification

- **Module design, not material properties, determines observed displacement**
  - Dimensions
  - Support
- **Material properties can change during lamination**
  - Orientation
  - Morphology
  - Structure
- **Material characterization can provide physical property information useful in proper module design**
  - Define engineering properties of interest.
  - Define relevant test methods
- **Results are configuration and load dependent**
  - Test acceleration can introduce unrealistic creep/flow mechanisms

Material Characterization (I)
Zero shear viscosity

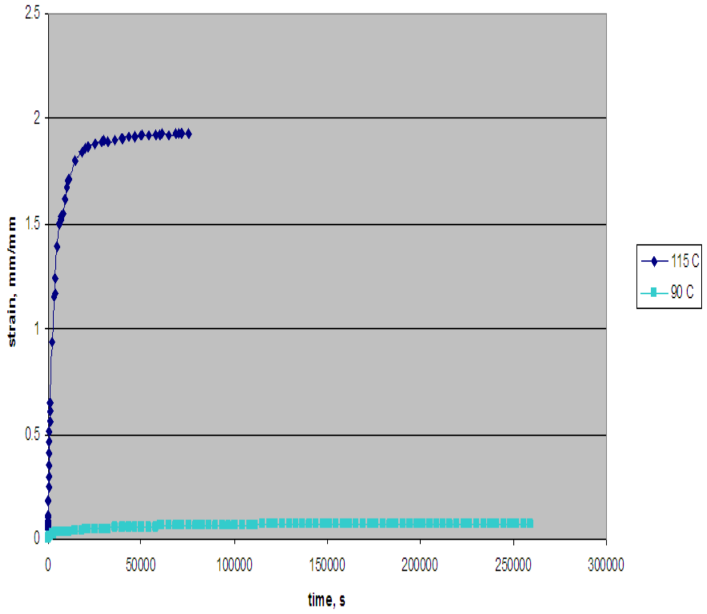
- **Estimate stresses on module/encapsulant and calculate lifetime displacement assuming viscous flow**
  - Measure zero-shear viscosity vs. temperature.
  - Couple measured viscosity to real-world temperature history and assumed load to calculate displacement over the lifetime of the module
- **Issues**
  - Temperature dependence of viscosity may not follow simple activation energy model.
  - Extrapolation through material transitions (e.g., crystallization) is NOT valid. New/unrealistic deformation mechanisms are introduced. Results cannot be generalized.
  - Thermoplastic encapsulants are designed to flow during lamination but “solidify” below maximum use temperature by one or more mechanisms

Material Characterization (II)
Creep

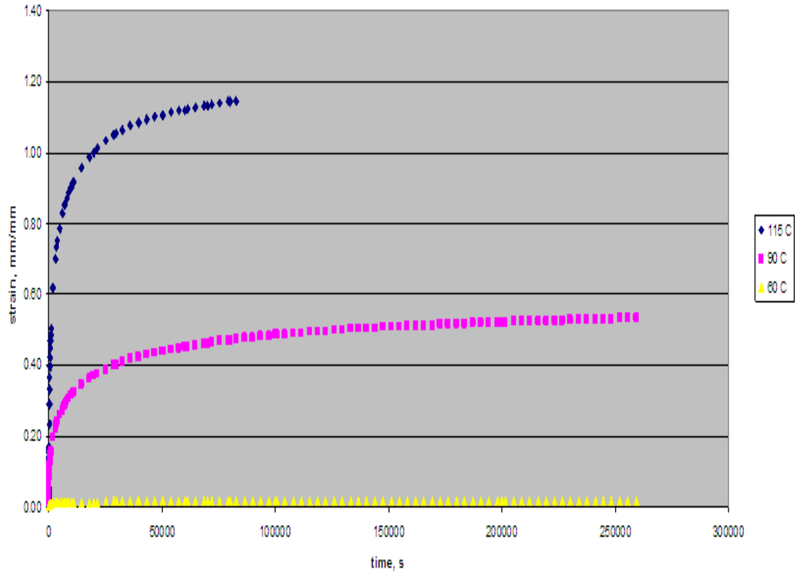
- **Estimate stresses on module/encapsulant and calculate lifetime displacement assuming viscoelastic creep**
    - Measure creep response over accessible range of time and temperature
    - Establish retardation spectrum using time-temperature superposition
    - Couple creep behavior to exposure history to determine lifetime displacement
- **Issues**
    - Test results dependent on specimen configuration and load
    - Phase transitions (e.g. crystallization) complicate data gathering and interpretation
        - Time-temperature superposition established for amorphous materials near glass transition
    - Establishing maximum test temperature

Creep under high load (~7X glass weight)

Encapsulant A

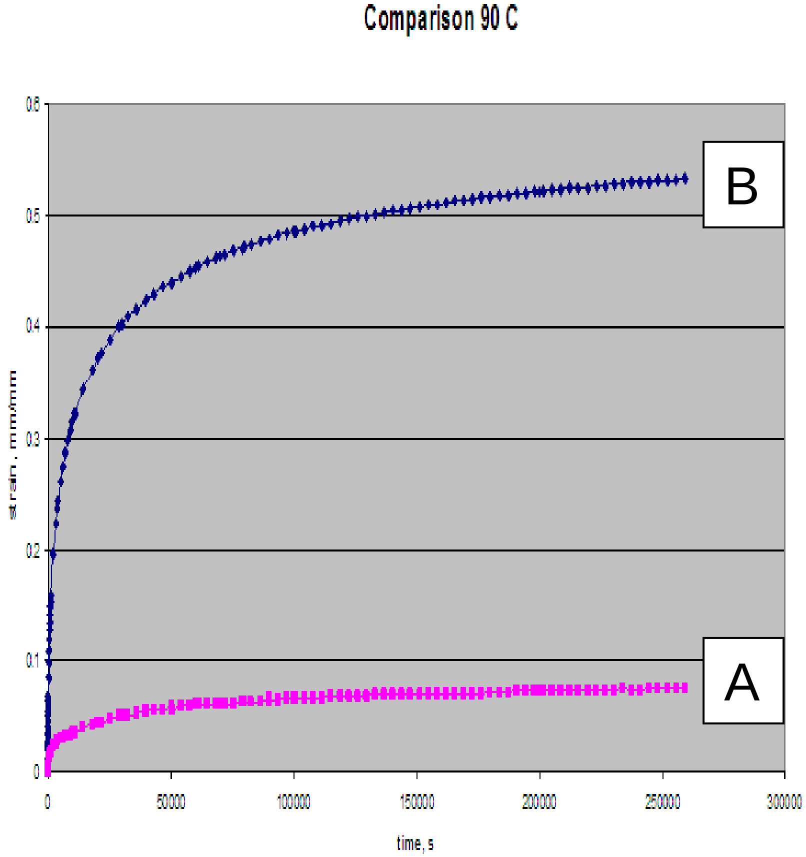


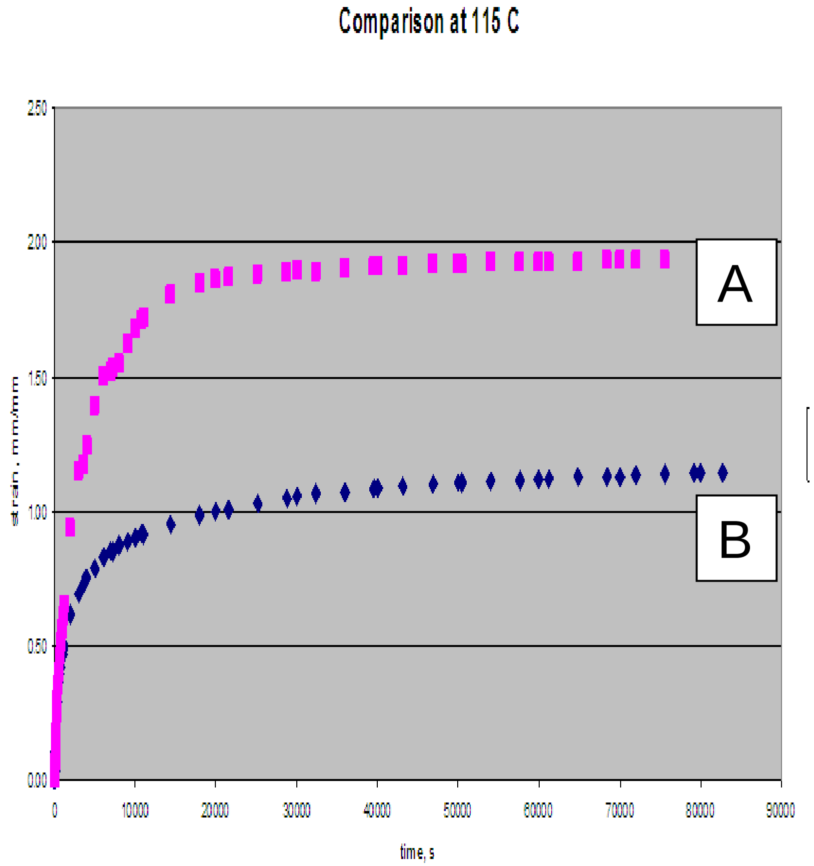
Encapsulant B



Thermoplastic encapsulants will creep under some temperature/stress loading conditions.

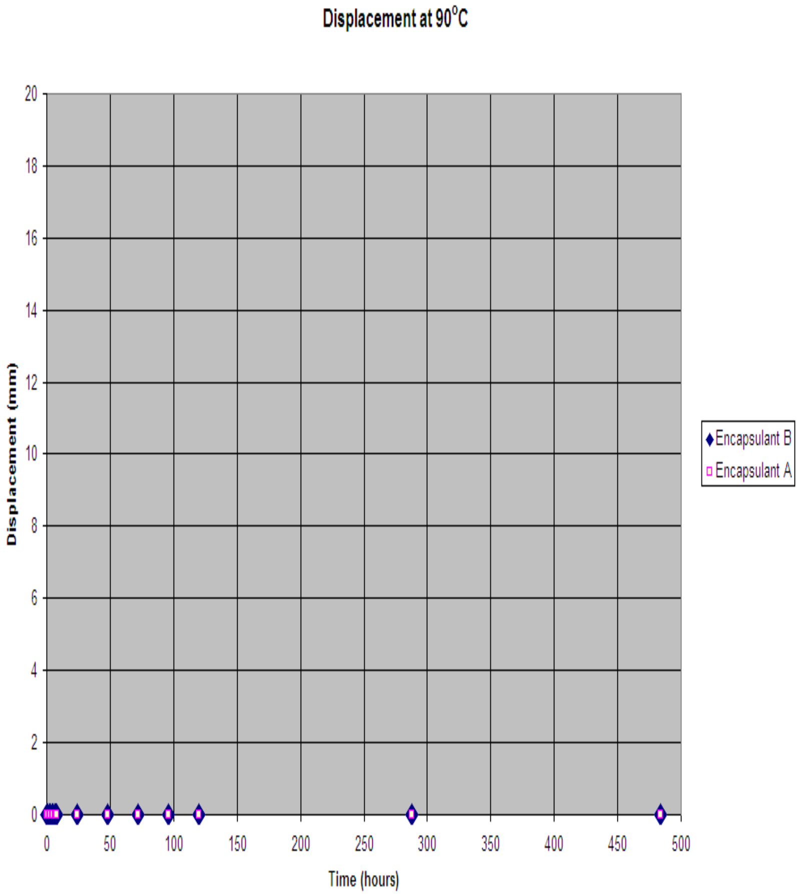
Effect of Test Temperature on creep
(High load – 7X glass weight)

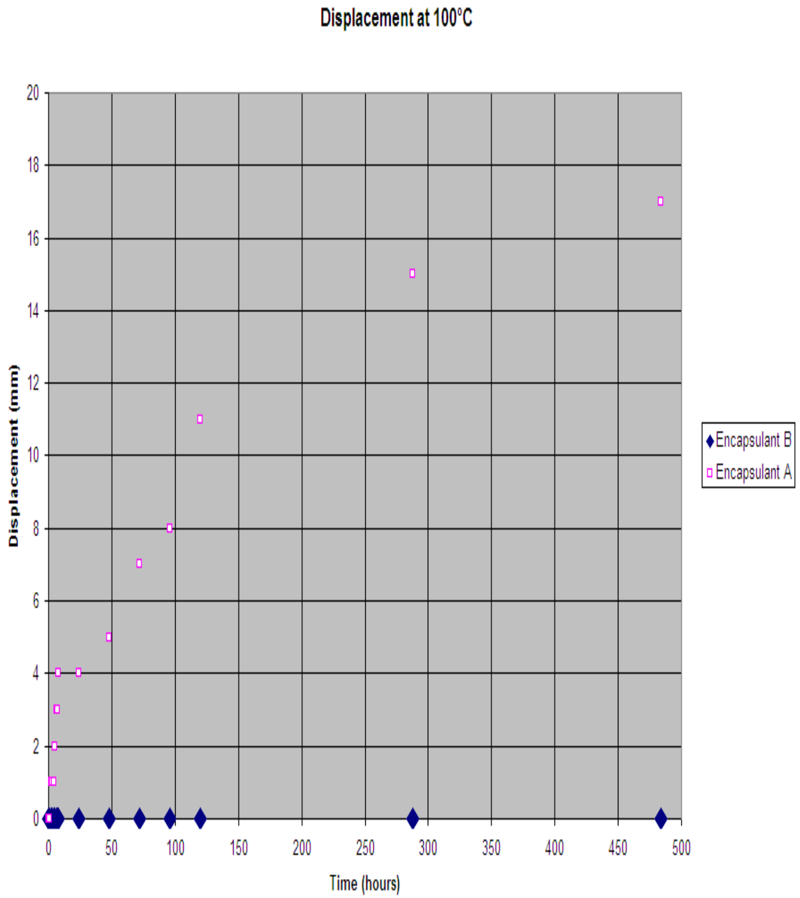




Performance depends critically on test temperature

Effect of Test Temperature on creep
(Normal load – 1X glass weight)





Performance depends critically on test temperature

Module Test Result

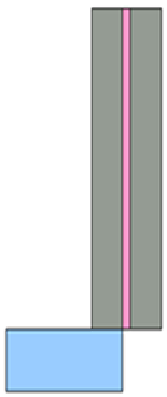
Method:

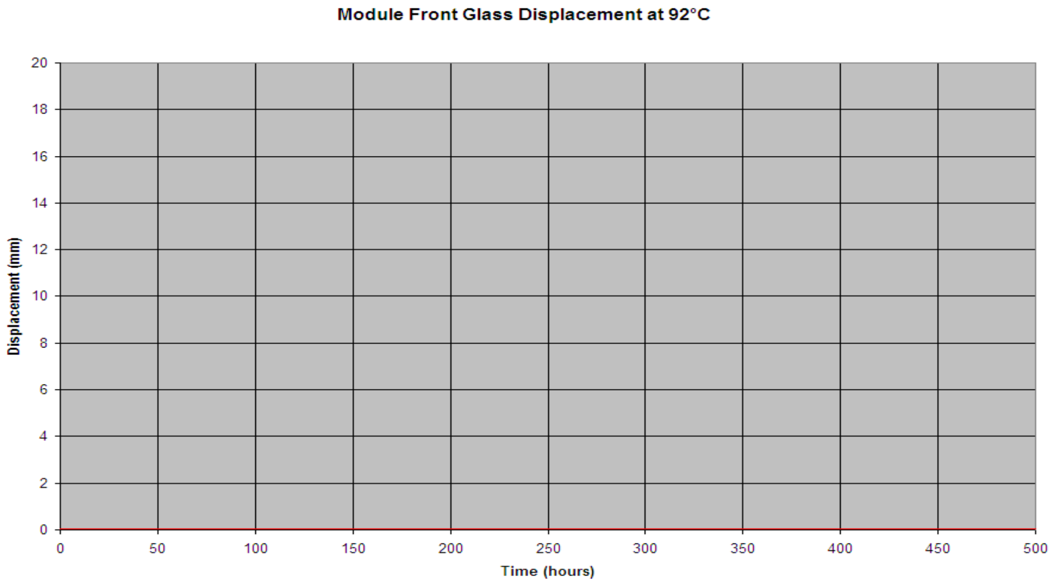
Mount module vertically supporting only back glass

Measure displacement of front glass after 500 hours at 92°C

Result:

No displacement observed





Recommendations

- **Only module tests should be used to assess acceptability of displacement over lifetime**
  - Load to extreme, but PHYSICALLY MEANINGFUL, conditions, e.g.,
    - Vertical configuration
    - T_{max} (TBD)
  - Measure contact distortion, internal displacement, etc.

- **Identify failure mechanisms and define material characterization tests (e.g., viscosity, creep, DMA, TMA) to provide data useful in the design of safe modules.**

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