Stress Development in Silicate Thermal Control Coatings

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Introduction

- Loss of structural integrity either through adhesive or cohesive failure has plagued hardware coated with silicate coatings
  - Impact surface thermo-optical properties
  - Particle contamination generation and impact to subsystems
- Causes for this loss of adhesive properties has been anecdotally identified in processing deficiencies
  - Inadequate surface preparation
  - Improper application conditions (dryness, applied to quickly, etc)
  - Improper curing conditions and durations
  - Dry film thickness to thick
- Current work attempts to determine fundamental environmental causes for these failures by looking at stress development within the coating

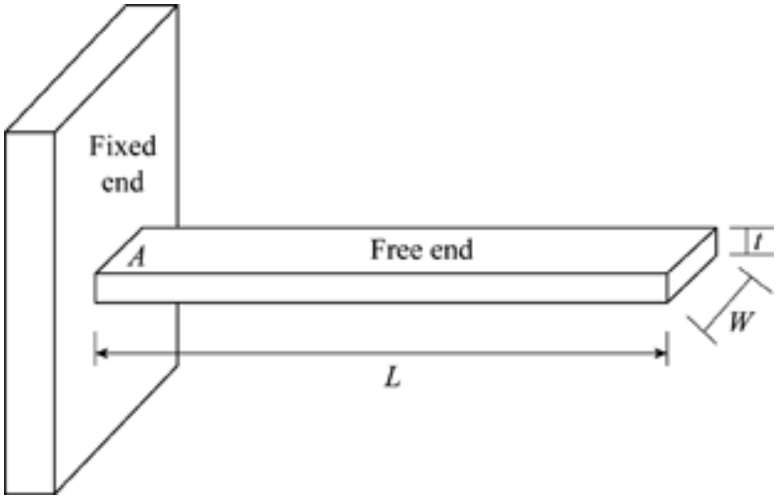
Causes of Cracking in Silicate Coatings

- Thermal Changes (Insignificant)
  - CTE Mismatch
- Humidity Changes
  - Evaporation of water within the coating
- Pressure Changes
  - Evaporation of water within the coating

- Stress develops within the coating before it cracks
  - The likeliness that it will crack is related to the level of stress build up

How can we quantify this stress?

- A shrinking thin film develops compressive stress that can be measured by flexural stress in a bending beam.
- Stoney's equation converts these changes into stress.
- For a small deflection:
  - $\Delta\, \sigma_{zz} = \Delta \mathbf{d} * (E_s t_s^3)/(3L^2(1-v_s)t_f t_t)$
- For a large deflection that results in a uniform curvature:
  - $\Delta\, \sigma_{zz} = \Delta \mathbf{(1/R)} * (E_s t_s^3)/(6(1-v_s)t_f t_t)$



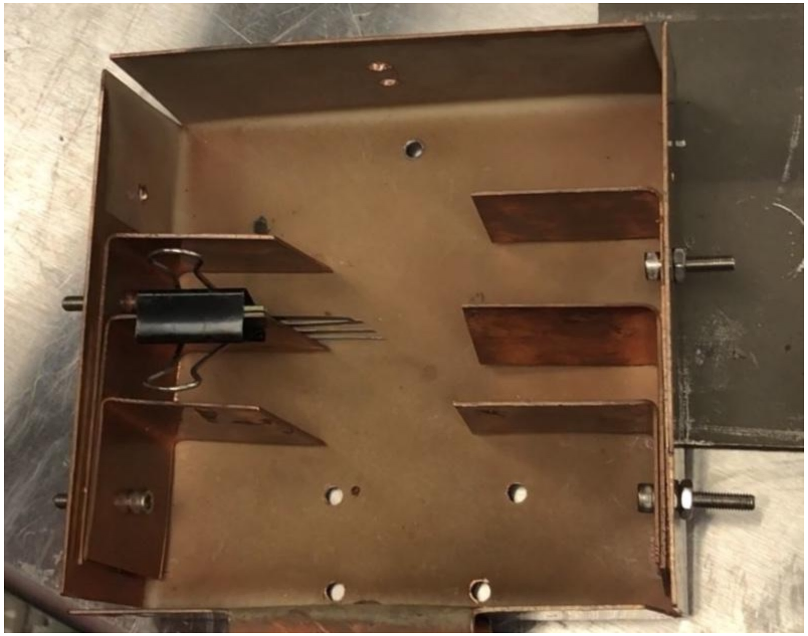
What factors can influence measurements?

- Presence of a primer
- Dimensions of base
- Rigidity of substrate
- Thickness of film

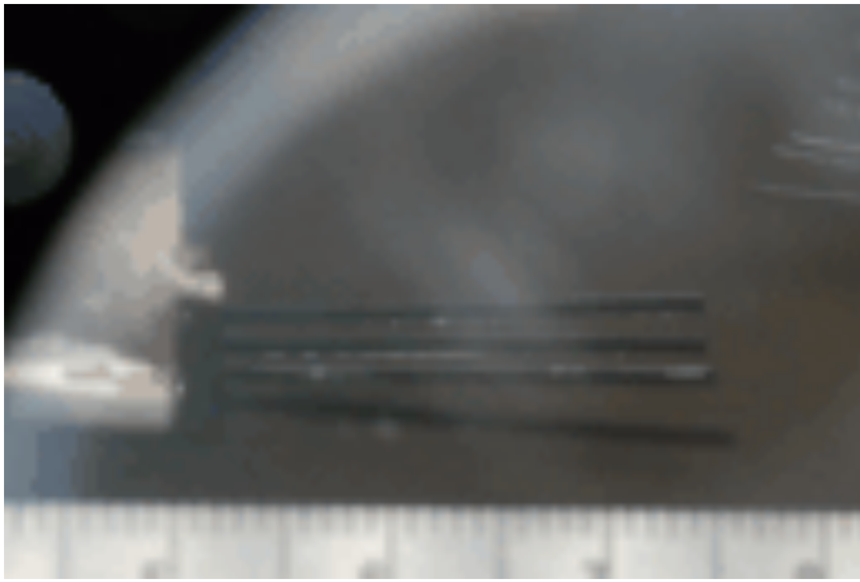
Z93C55 Coated Kapton Undergoing Vacuum Depress

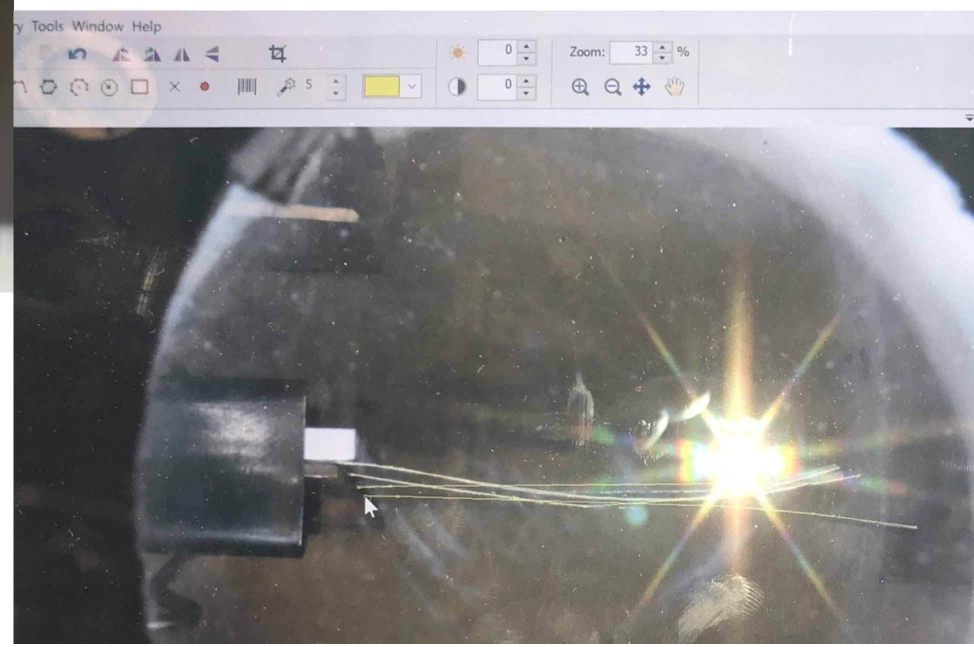
How we analyzed deflection/curvature?

- Digital images taken at regular intervals
- Deflection measured as length from original sample
- ImageJ/Digimizer will provide length and curvature change



Articles Under Test

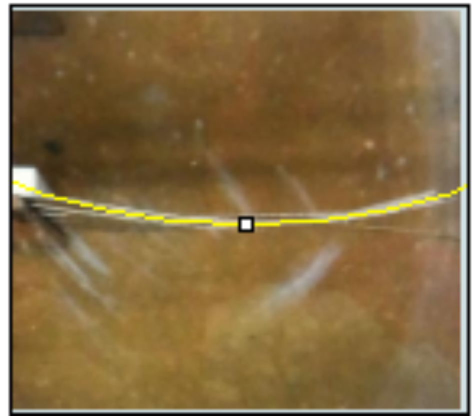




Measured Values

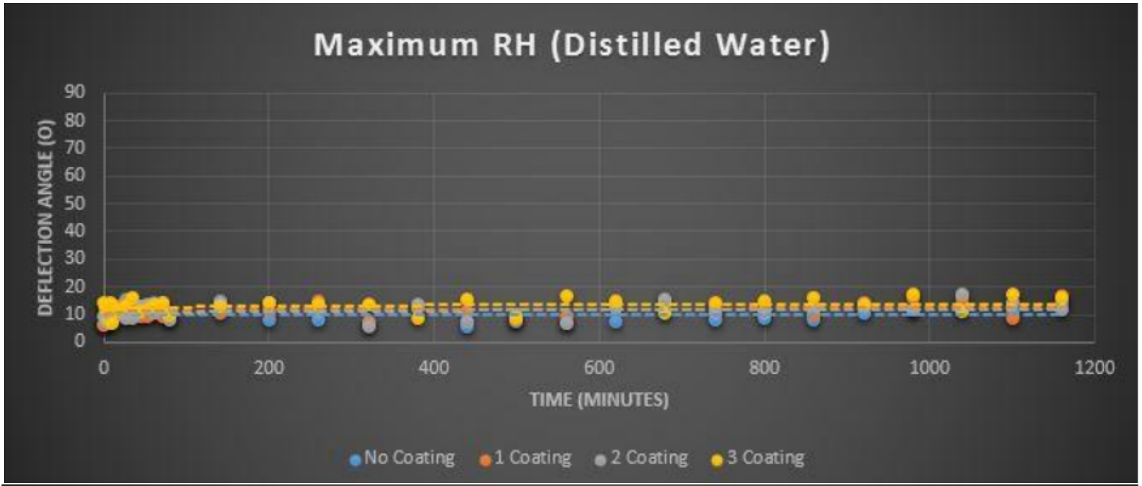
- Radius of Curvature:
  - Data given: Area of traced circle in pixels
  - $^*R = 1/\sqrt{(\text{Area}/CF)/\pi}$
- Deflection
  - Data given: Change in length
  - $^*d = \text{Length}/CF$

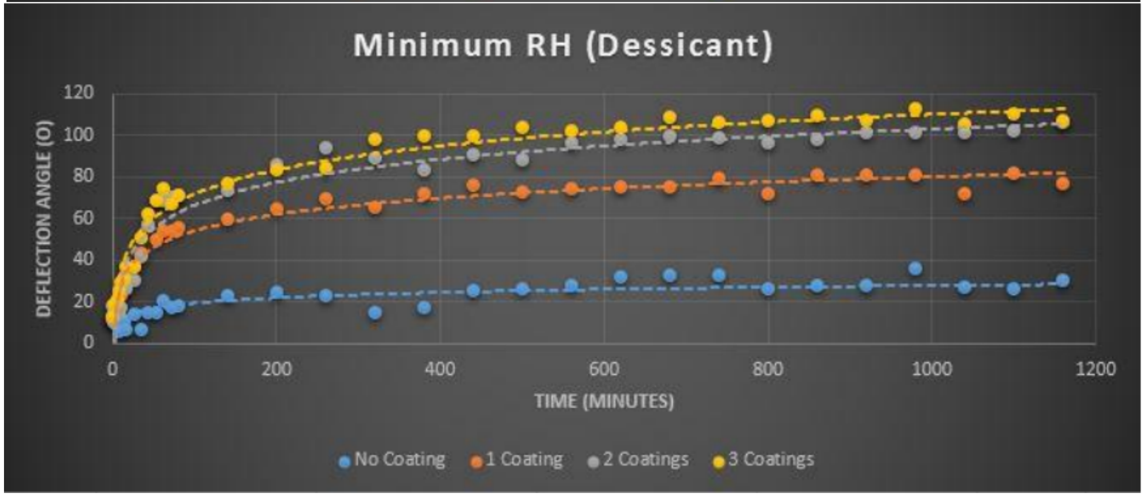
*CF = Conversion factor



Humidity

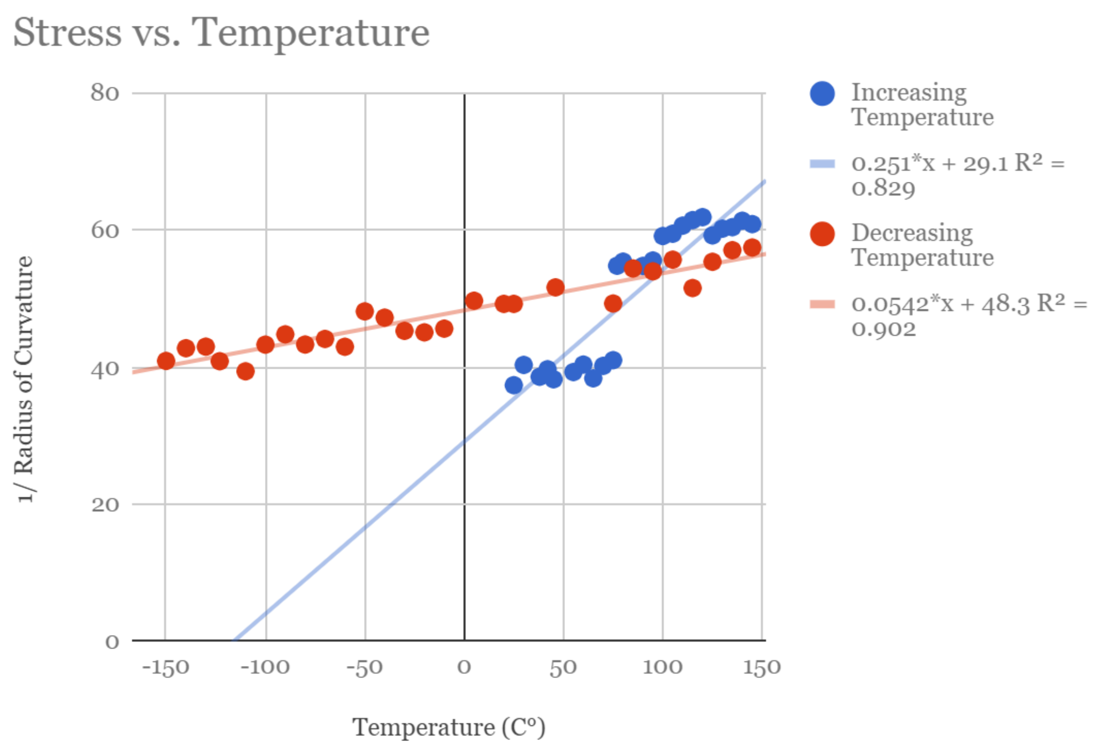
- As humidity increases, deflection angle decreases.
- Deflection angle is a measurement that is not as universal as stress, but still indicates a trend.





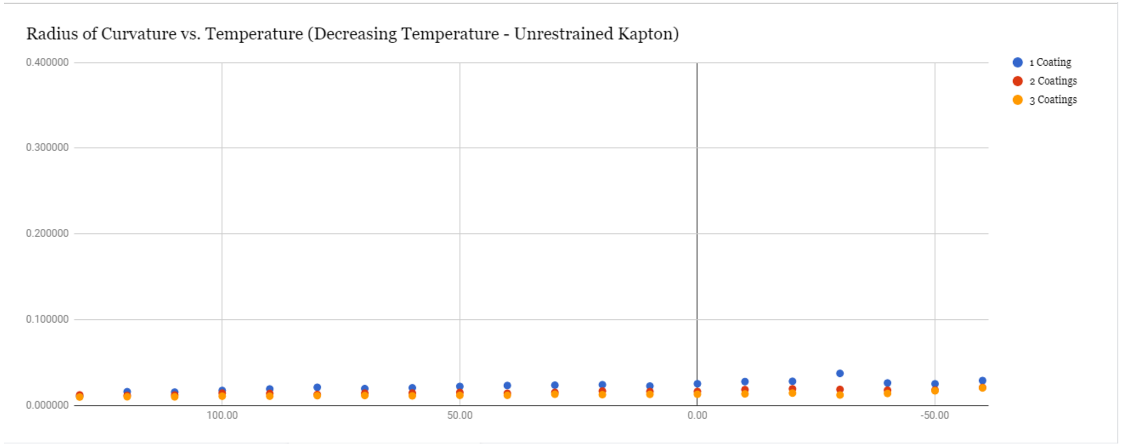
Thermal Cycling

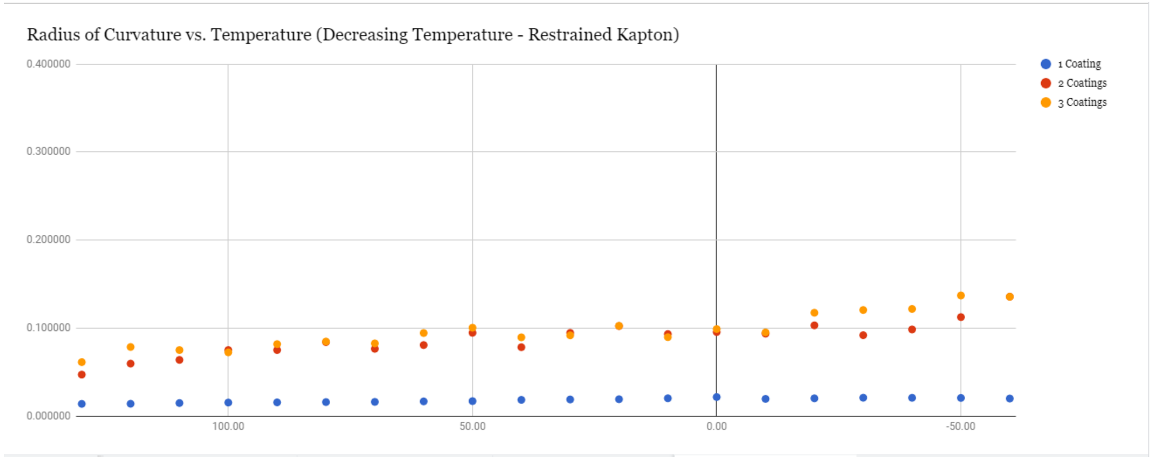
- Taken at rough vacuum
- Temperature increased with resistors and decreased with LN2.
- Stress development is faster when increasing temperature because of initial water removal.



Restrained vs. Unrestrained

- Kapton restrained during curing develops more stress than Kapton that is unrestrained during curing



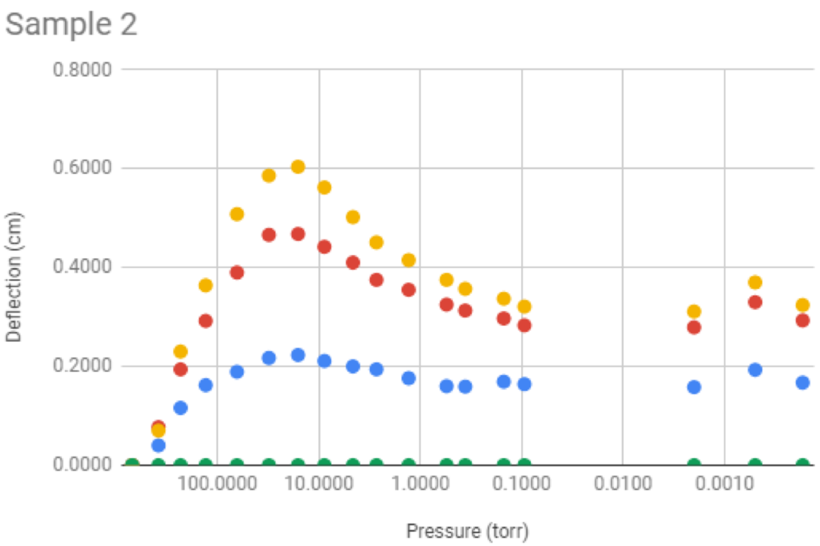


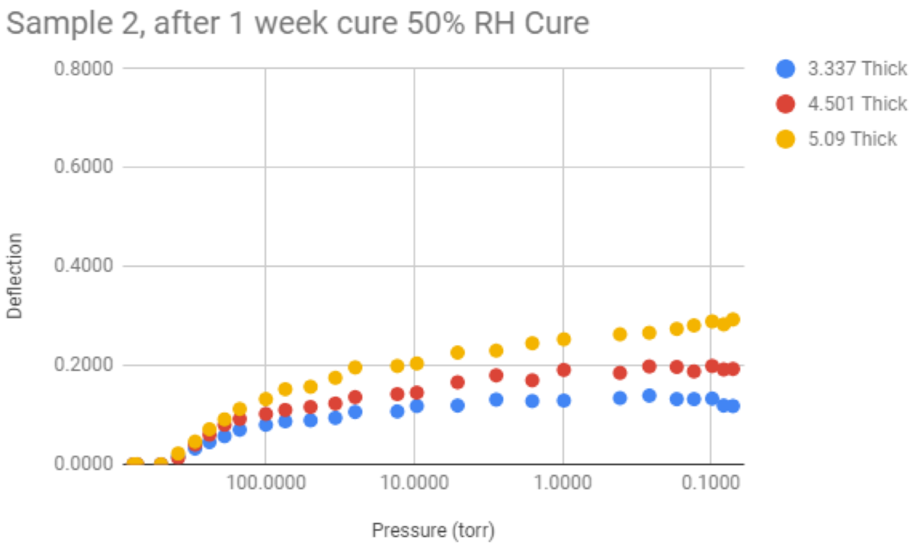
Presence of Repair Characteristics

Environmental Condition Undergone	Average Maximum Stress Change (kPa)
1 week Cure 50% RH	-136.7
1 Vacuum test, 1 day 100% RH, 50% RH	35.0
1 Vacuum Test, 1 week 50% RH, 3 days 100% RH, 1-5 days 50% RH	-102.8
2 Vacuum Tests, 1 week 50% RH, 3 days 100% RH, 3 days 50% RH	-163.0

- Each stress change is assumed to be caused by water removal
- Repair is observed after a brief period of high humidity and one vacuum test.
- Test itself is destructive to the coating
- Repair is limited

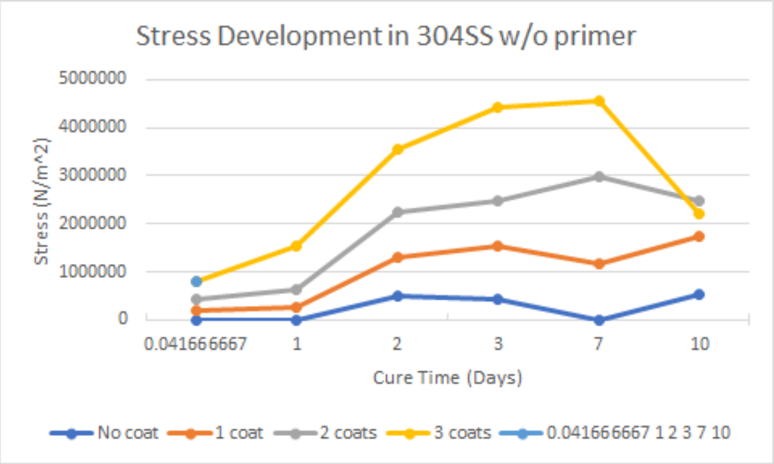
A Deeper Look at a "Broken" Sample

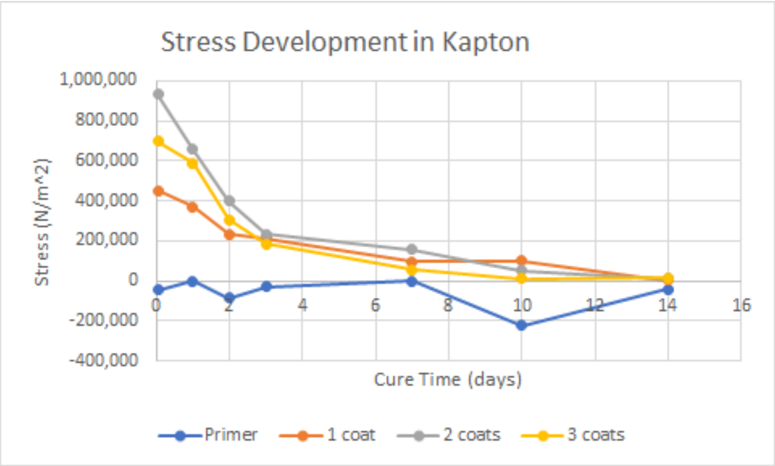




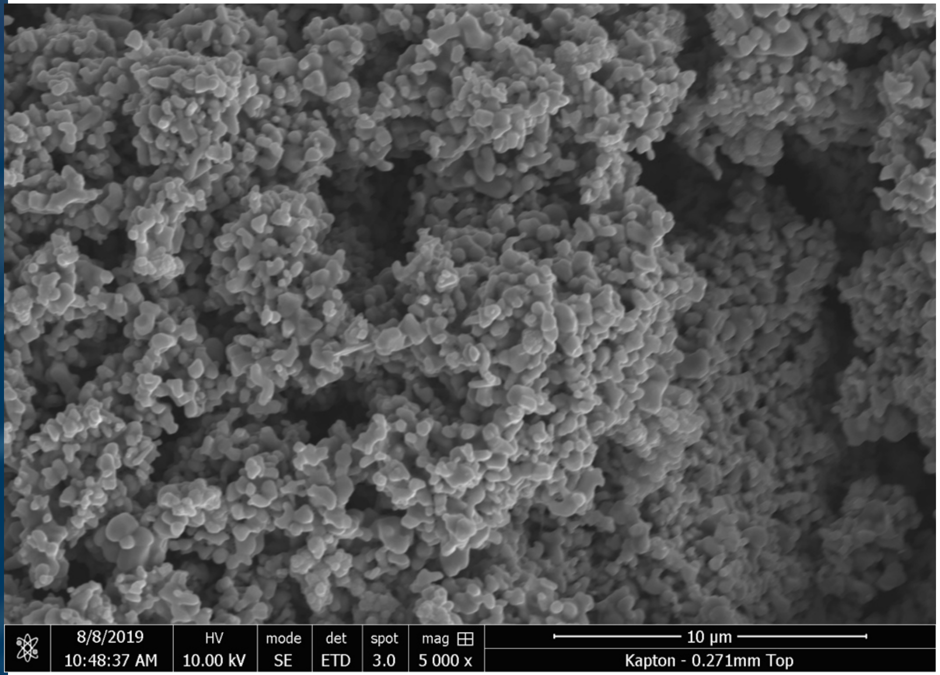
IPA as a Stress-Measuring Tool

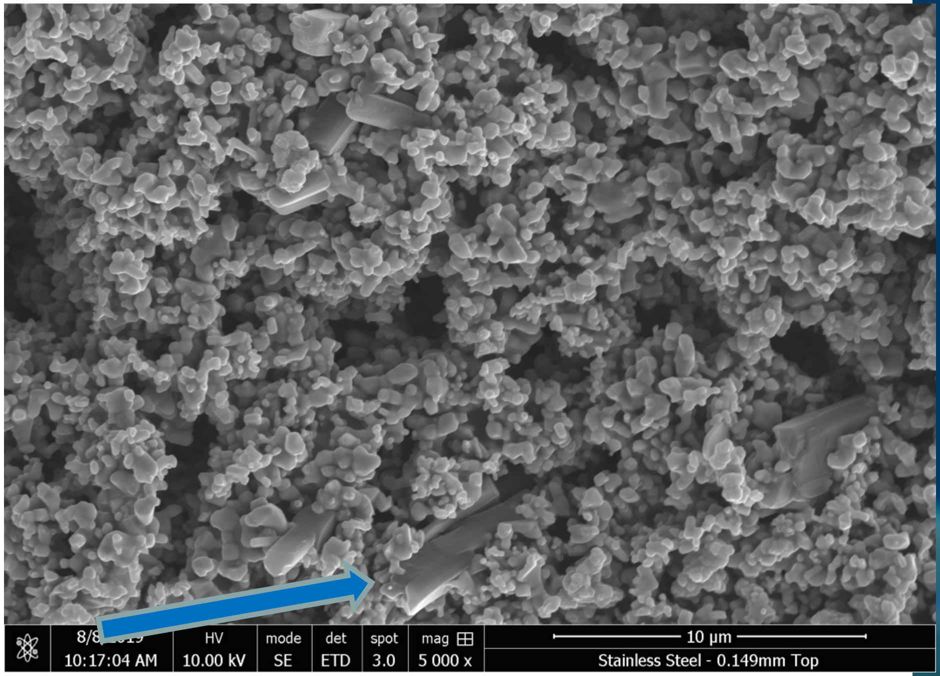
- Immersed in IPA at various times during curing
- Stress development decreases in Kapton over time, but increases in Stainless Steel (304SS) over time
- Quickly and non-destructively indicates if a batch of silicate coating has fully dried





Structure of Z93C55 in Kapton vs 301SS





Conclusions

- Stress development in vacuum is significant enough to result in deflection followed by stress relief (cracking)
- Higher humidity results in lower stress development during curing
- Thermal cycling may cause stress through water evaporation
- Limited repair is possible after exposure to a high humidity environment
- IPA could be used as a stress measurement surrogate to vacuum exposure

Future Work

- Analyze the cause of alternative structure of Z93C55 in Kapton vs. Stainless Steel.
- Other solvents can be analyzed as potential stress-measuring tools.
- Healing can be analyzed through manual cracking
- Saturated gas environment of IPA can further elaborate how IPA takes in water from the Z93C55.

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Backup Slides

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