

Can the Boeing Wedge Test be used with rubbery Edge Seals and analyzed using Griffith's Criterion?

Introduction

Three widely commercialized butyl edge seals with good field performance were used to explore how sealants behave using a series of wedge sizes. Monitored adhesive delamination and thickness changes vs time. This exploratory work is being used to support development of a wedge test for PV Edge Seal Durability. The goal was to be able to calculate Griffith's Criterion (G_c), described as Adhesive Fracture Toughness.

Samples

- 1" x 8" low iron glass 3.25 mm thick
- 4" glass/4" adhesive ~0.6 mm thick (used 0.5 mm spacer)
- 4 wedge sizes 1.0 mm 1.25 mm 1.50 mm 1.75 mm
- Wedge placed 3.75" from adhesive junction



Conditions & Measurements

85°C DRY QUV UVA lamps 1.18 irradiance ~1.74 Suns - constant on, no dark Sealant Temperature: Black=93°C Gray=88°C
UV through glass measurements (@ adhesive interface)
@254 nm = 25.5 μW/cm² @308 nm = 117 μW/cm² @365 nm = 19.7 mW/cm²
QUV @ 64 days exposure = 99 kWh/m² ≈ 1.2 yrs Florida Sun total UV

Fracture is any crack growth or branching noted by adhesive delamination or cavitation). Observed as bubble formation which propagates.

Equation & Calculations

Griffith's Criterion G_c "Fracture Toughness" $G_c = \frac{3Et^3h^2}{16a^4}$
E= 72 GPa low-iron glass
t= 3.25 mm beam thickness
h= wedge size - initial adhesive thickness (varies 0.55-0.60 mm)
a= distance from wedge to longest delaminated point

If no failure, then the G_c Fracture Toughness energy is higher than the value shown. G_c in J/m²

Conclusions

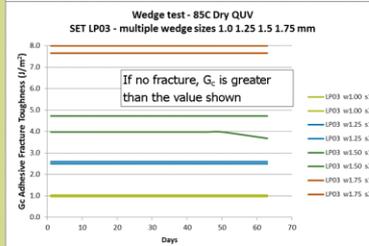
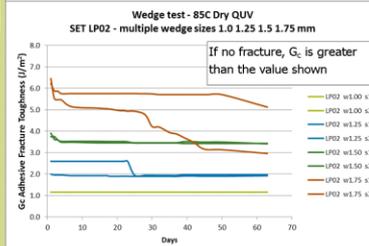
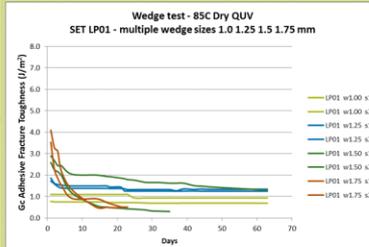
- ⇒ Reproduce some failure modes seen in Damp Heat modules
- ⇒ "Crack tip" is not distinctive: bubbles following cavitation eventually combine and grow
- ⇒ Too large a wedge increases the strain rate beyond the time domain of creep
- ⇒ Oversized wedge creates rapid failure
- ⇒ Oversized wedge creates a failure mode not seen in the field
- ⇒ In order to study the effect of long UV exposure, the strain rate should not induce rapid failure
- ⇒ BWT with rubbery materials is not straightforward. There is a complex interaction of modulus, stress relaxation, applied strain and the work of adhesion
- ⇒ How to analyze the data and interpret the results needs discussion
- ⇒ Failure location can transfer between sides (front/back) resulting in shorter measurable delamination



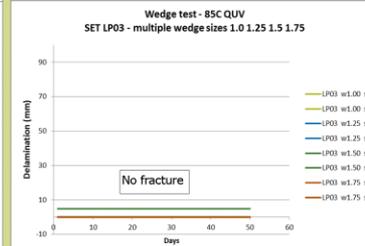
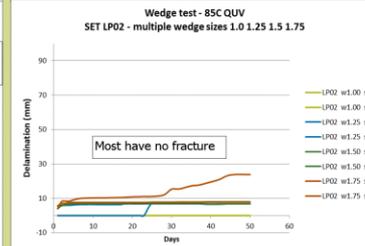
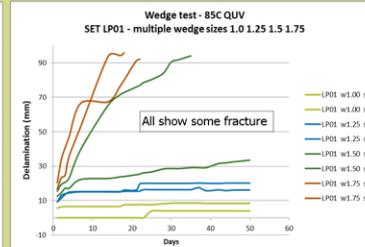
⇒ A more complex model may be needed to account for plastic deformation, a cohesive zone in front of the crack tip, dissipative energy (such as stress relaxation), etc.

- ⇒ Griffith's Criterion may be an oversimplification with rubbery materials
- ⇒ New sealants may be overengineered. Excessive strain yields no failure.

Fracture Toughness vs Time



Adhesive Delamination vs Time



LP01 wire 1.75 mm UV side



Adhesive failure pictured one side. Some fail both sides / less distance. Failure too rapid

LP02 wire 1.75 mm UV side



Some adhesive failure

LP03 wire 1.75 mm UV side

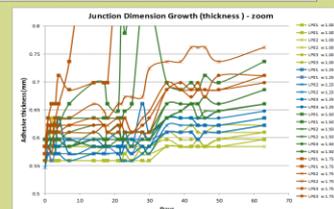


No adhesive failure even after 64 days

Thickness Change



- ⇒ Thickness measurements were taken at the Junction between glass and adhesive
- ⇒ Wedge size increased the thickness at the junction point within one day after wedge insertion
- ⇒ Initial growth (Day 1) is proportional to wedge size
- ⇒ Other variations due to measurement error and equipment used (changed at day 32)
- ⇒ No cohesive failure or cavitation noted in the adhesives (via back lighting)



Improvements Needed

- ⇒ Induce a sharp crack tip on the exposed side of the sample
- ⇒ Compare performance in multiple environments to see impact of the weathering
- ⇒ Since SET LP01, a functional edge seal in the field, shows some fracture at even the smallest wedge, a smaller wedge at 1.25 mm may be sufficient to induce failure for study of environmental effects of UV and humidity without overstraining the adhesive.

Acknowledgements

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