Sandia National Laboratories

Exceptional service in the national interest

Predicting Adhesive Failure Initiation of an Epoxy Underfill for Electronic Packaging Survivability

Authors: Kevin N. Austin, Jamie M. Kropka, Brenton Elisberg
Collaboration of Department 1833 and 1526 Sandia National Laboratories

SAND2012-4338C

Abstract

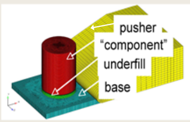
Designers want to be able to predict whether electronic components mounted to a printed wiring board (PWB) will remain functional over the life cycle of a device. This is a very challenging task, as even a single component, which may be a small part within a complex design, can be subject to multiple modes of failure. Possible failure modes may include: (1) failure within the component, (2) cohesive failure of the PWB, (3) adhesive failure of the component from the PWB and (4) solder joint failure. This work focuses on one aspect of the problem: predicting failure of the polymer underfill that bonds a surface mount component (SMC) to a PWB. A simplified SMC geometry, a metal cylindrical plug bonded to a metal plate, is used for experimentation in order to enable validation of finite element analysis predictions of the test. Two unique tests have been conducted: (1) application of a mechanical load directly to the plug and (2) application of a bending load to the plate, in a four point bend fixture. The experimental load at which the underfill bond fails is correlated to local polymer strains in the bond, and this information is used to define a failure metric. The ability of the metric to predict failure under other, unique conditions is also evaluated.

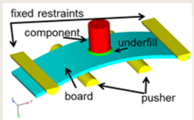
Test Geometry and Modes of Loading

- Define a representative simplified geometry that focuses on failure on the polymer underfill.

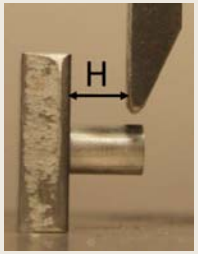
Component Loading — **Board Flexure**

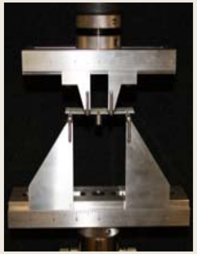
Models





Experiments





Polymer Non-Linear Viscoelastic Model

$$\underline{\underline{\sigma}} = \frac{\rho}{\rho_{ref}}\left[K_d(T)\int_0^t ds\ f_v(t^*-s^*)\frac{dI_1}{ds} - L_d(T)\int_0^t ds\ f_v(t^*-s^*)\frac{dT}{ds}\right]\underline{\underline{I}} + \frac{2\rho G_d(T)}{\rho_{ref}}\int_0^t ds\ f_s(t^*-s^*)\times\left[\underline{\underline{R}}(t)\cdot \underline{\underline{d}}_{dev}(s)\cdot \underline{\underline{R}}^{-1}(t)\right] + \frac{\rho}{\rho_{ref}}\left[K_\infty(T)I_1 - L_\infty(T)\{T-T_{ref}\}\right]\underline{\underline{I}} + \frac{2\rho G_\infty(T)}{\rho_{ref}}\left[\underline{\underline{R}}\cdot\underline{\underline{\varepsilon}}_{dev}\cdot\underline{\underline{R}}^{-1}\right]$$

$$N = \left[\{T-T_{ref}\} - \int_0^t ds\, f_v(t^*-s^*)\frac{dT}{ds}\right] + C_3\left[I_1 - \int_0^t ds\, f_v(t^*-s^*)\frac{dI_1}{ds}\right] + C_4\int_0^t\int_0^t ds\,du\, f_s(t^*-s^*, t^*-u^*)\,\underline{\underline{d}}_{dev}(s):\underline{\underline{d}}_{dev}(u)$$

$$\log(a) = -\frac{C_1 N}{C_2'' + N}$$

$$t^* - s^* = \int_s^t \frac{dx}{a(x)}$$

- Simplified Potential Energy Clock (SPEC) model- Accurately predicts complex polymer responses including:
  - Temperature Dependent Yield
  - Enthalpy Relaxation
  - Thermal Expansion
  - Non-linear Creep
  - Physical Aging

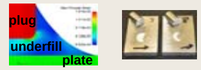
Adolf et. al., *Polymer*, 50 (2009) 4257-4269

Component Loading

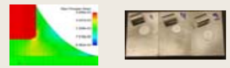
- Experiments defined a failure mode dependent on H
- SPEC model predicted a locus of failure initiation at the component interface

(≈ at failure)

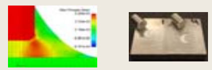
H = 0.025"



H = 0.260"



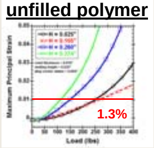
H = 0.105"



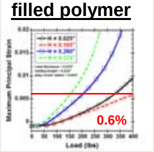
H = 0.374"

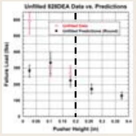
- Maximum principal strain (MPS) values of 1.3% and 0.6% for unfilled and filled epoxy respectively, are used to predict the load at failure.

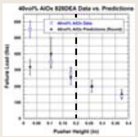
unfilled polymer



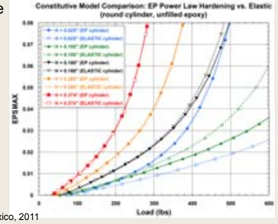
filled polymer







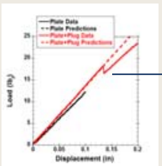
- At low H, plug deformation compresses the polymer underfill. The compression is more prevalent when the plug exhibits plasticity.
- Above H ≥ 0.20", polymer underfill strain is not sensitive to an elastic and plastic plug at the experimental loads at failure



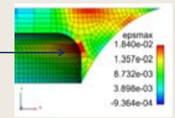
Elisberg, B. Thesis, University of New Mexico, 2011

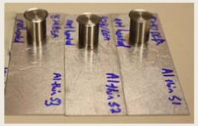
Board Flexure

- Predictions match experimental measurements of macroscopic Load-Displacement well

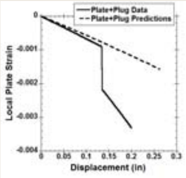


EPSMAX at Failure

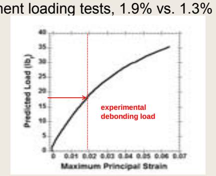


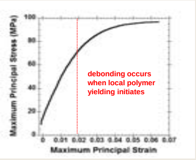


- The local measured plate strain correlates well with predictions



- The local polymer response suggests a maximum principal strain failure criterion comparable to the component loading tests, 1.9% vs. 1.3%





Conclusions

- Mode of loading affects both the load required to initiate failure and the mode of failure within the polymer bond
- A strain based metric was successful in predicting initiation of failure in some instances, but not others.
  - Maximum Principal Strains (MPS) of 0.6% for filled epoxy and 1.3% to 1.9% for unfilled epoxy were used as a failure metric

Future Efforts

- How universal is the strain based metric proposed here? Does it depend on mesh density for these high strain gradient problems?
- How relevant is underfill debonding to actual surface mount capacitor failure? Does failure initiate in the polymer underfill, in the solder, in the printed circuit board, or in the capacitor?

U.S. DEPARTMENT OF ENERGY — NNSA National Nuclear Security Administration

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.