

Thermal Mechanical Fatigue of a 56 I/O Quad-Flat Nolead (QFN) Package*

Paul Vianco and Mike Neilsen

**Sandia National Laboratories
ptvianc@sandia.gov, mkneils@sandia.gov**

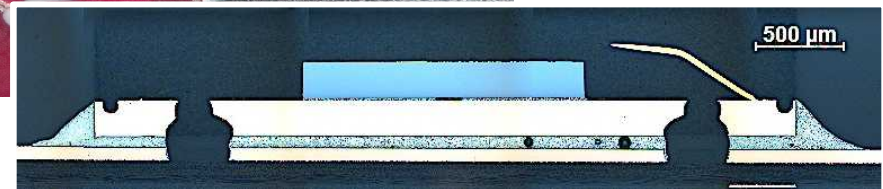
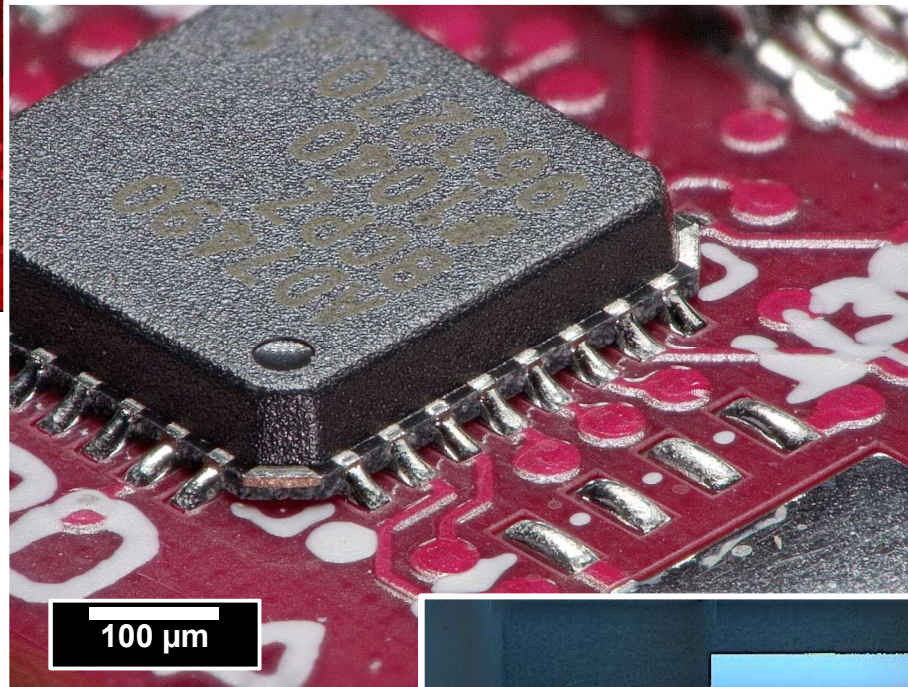
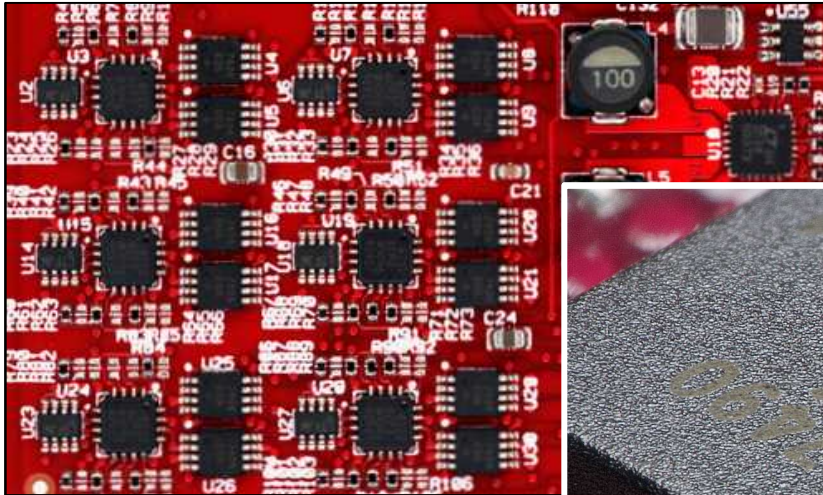


Outline

- **Introduction**
- **Finite Element Models**
- **24 I/O LCC Lifetime**
- **56 I/O QFN Lifetime**
- **Effects of Voiding**
- **Conclusions**

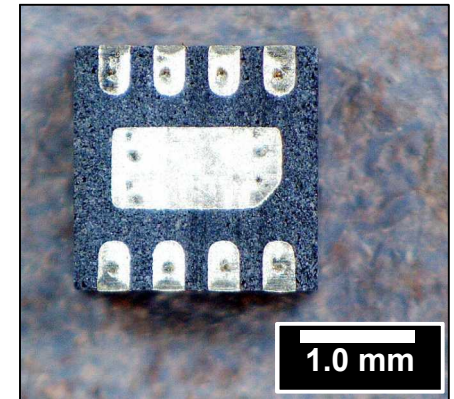
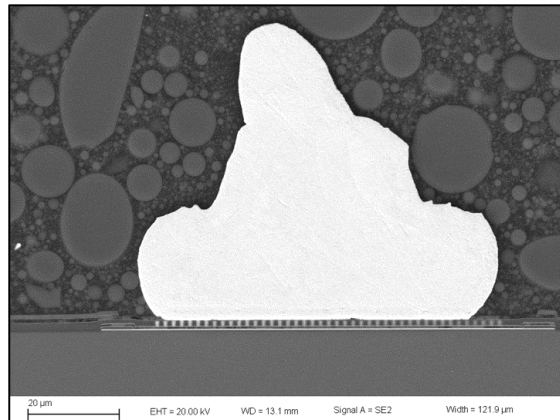
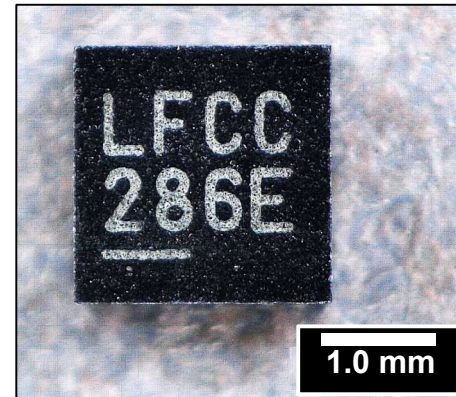
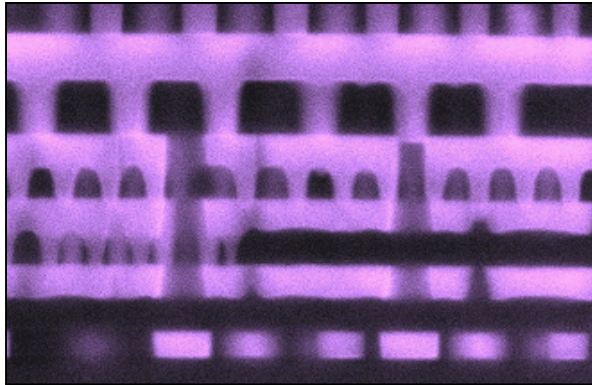
Introduction

- ◆ The **quad-flat no-lead (QFN) package** has been instrumental in the miniaturization and functionality of consumer products.



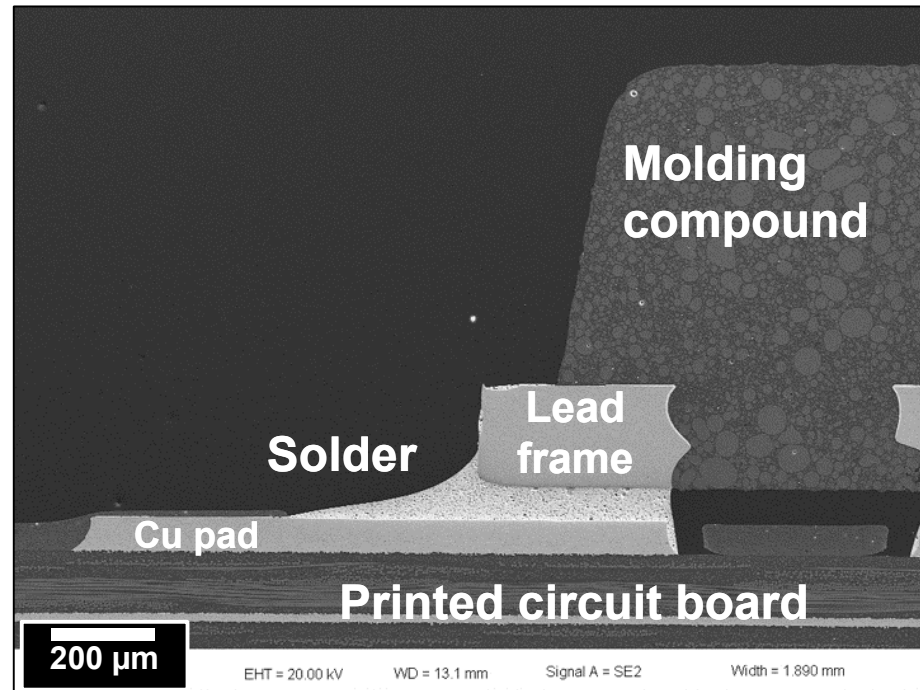
Introduction

- ◆ The **military, space, and satellite electronics communities** are reluctant to introduce new package types without a demonstration of their **long-term reliability**.
- ◆ A reliability assessment begins with **device performance**.



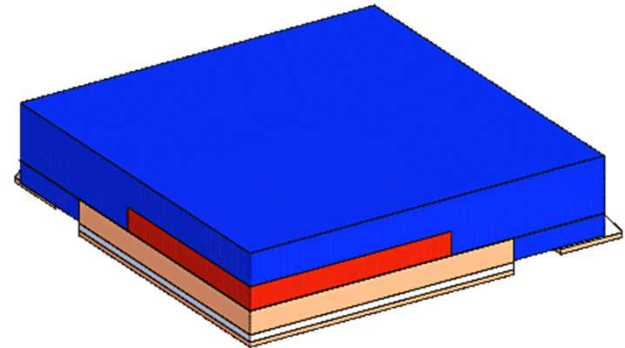
Introduction

- ◆ Besides device reliability, there is also the need to understand the long-term performance of **second-level interconnections**.
- ◆ In a “catch-22” scenario, programs are reluctant to support the **accelerated aging tests** needed to qualify a component.
- ◆ The alternative approach is to use **computational modeling** to get that “95% answer” needed for the go-ahead to full development.

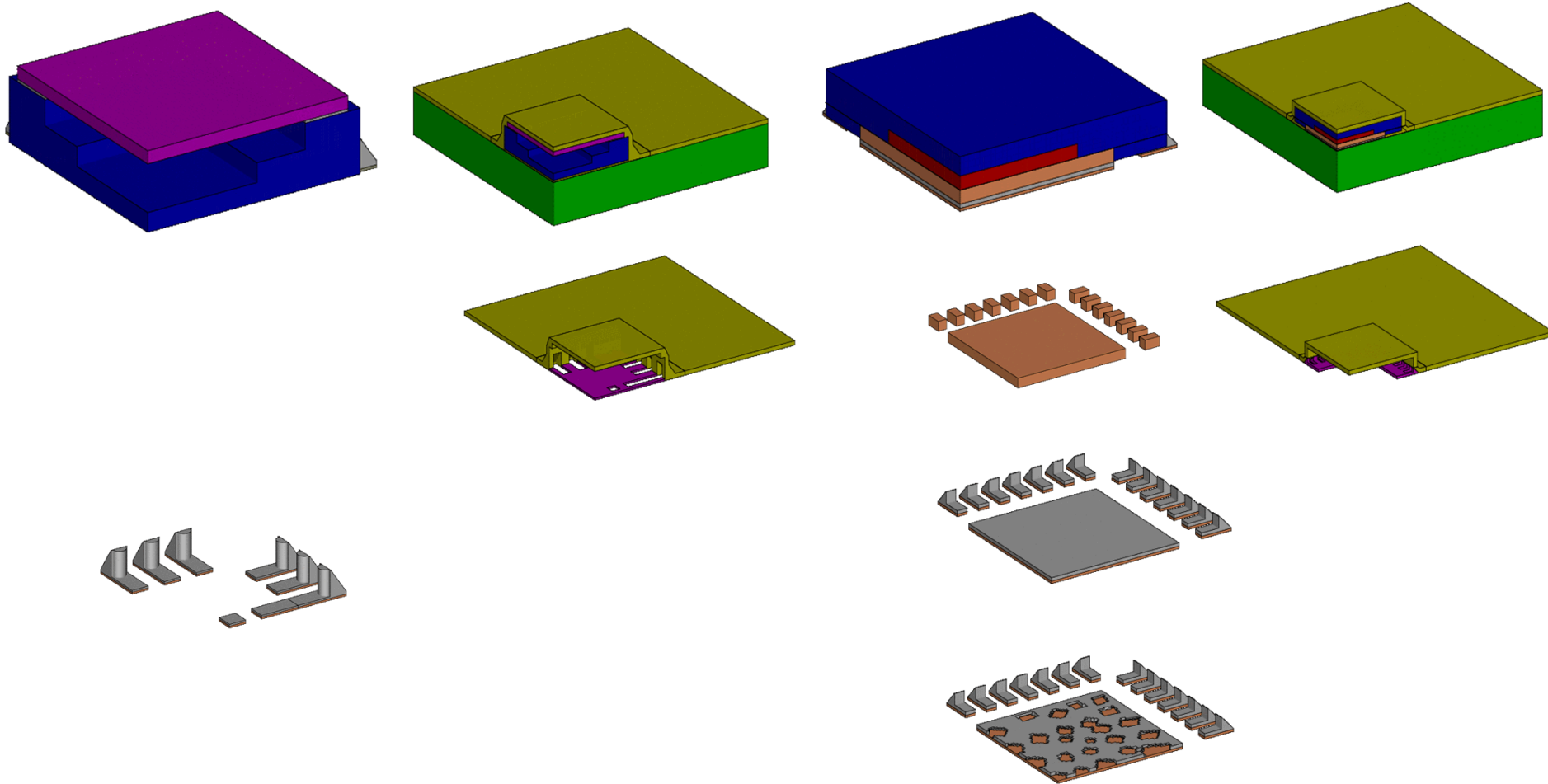


Problem

- ◆ A transitioning was being considered from the “tried-and-true” leadless ceramic chip carrier (LCCC) to the plastic quad no-lead package (QFN).
- ◆ The computational model approach was required in order to address this variable space that would present, otherwise, an intractable experimental study:
 - LCCC
 - PQFN
 - Underfill
 - Conformal coating
 - Encapsulating foam

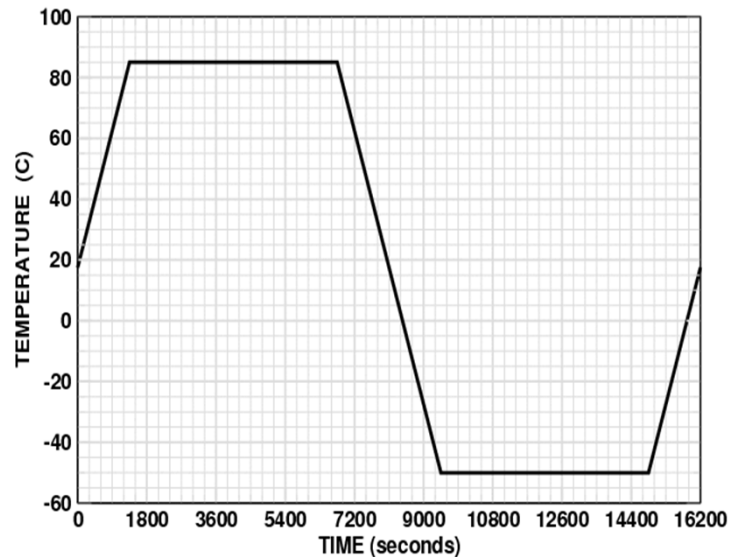


Finite Element Models



Models of $\frac{1}{4}$ of LCC and PQFN with Variations in Conformal Coat and Underfill

Temperature History



$$N_f = \left(\frac{1.14}{\Delta\gamma_p} \right)^{\frac{1}{0.51}} = \left(\frac{1.31636}{\Delta EQPS} \right)^{1.96078}$$

Reference: H.D. Solomon, 'Fatigue of 60/40 Solder,' *IEEE Trans. on Components, Hybrids, and Manufacturing Technology*, Vol. CHMT-9, No. 4, December 1986.

Material Parameters

Table 1. Material parameters for elastic materials.

Material	Young's Modulus (MPa)	Poisson's Ratio	Thermal Expansion Coefficient (1/°C)
Copper	117,241	0.350	17.50×10^{-6}
QFN Die	184,828	0.278	2.80×10^{-6}
QFN Molding	27,000	0.350	8.00×10^{-6}
LCC ceramic	282,759	0.210	6.67×10^{-6}
LCC lid	139,310	0.346	5.40×10^{-6}
LCC lid solder	59,310	0.405	15.88×10^{-6}
Conformal Coat*	28.0	0.497667	222.0×10^{-6}
Underfill*	7,695	0.350	38.00×10^{-6}

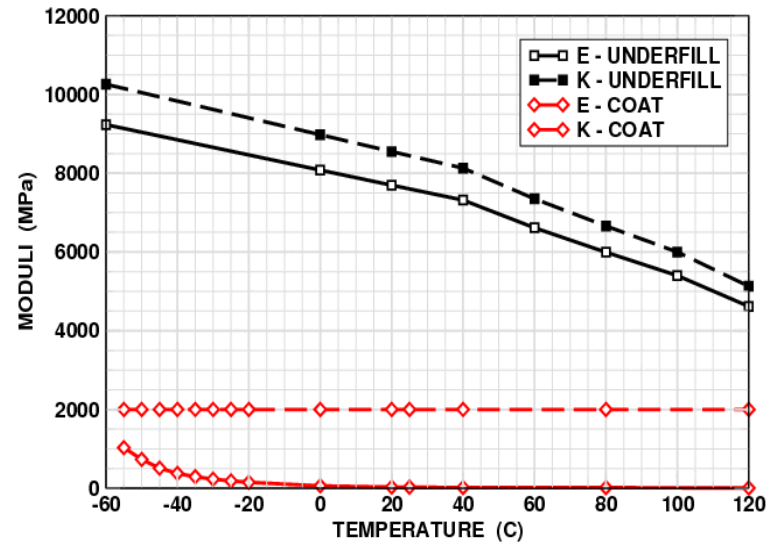


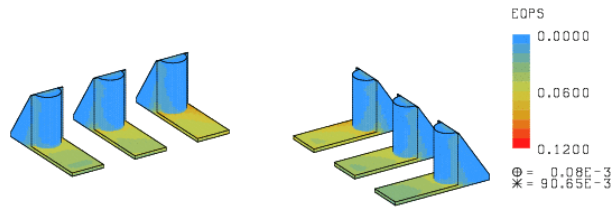
Table 2. UCPD material parameters for Sn63-Pb37 solder.

Temperature (°C)	-60.0	21.0	100.0
Young's Modulus (MPa)	48,276	43,255	36,860
Poisson's Ratio	0.38	0.39	0.40
Thermal Exp. Coef. (1/°C)	25.0×10^{-6}		
Flow Rate, f	4.14×10^{-20}	1.88×10^{-9}	2.21×10^{-5}
Sinh Exponent - p	7.1778	4.2074	3.7151
Iso. Hard. (MPa ^{A3+1})	270.67	193.44	167.76
Iso. Recov. (1/MPa-sec)	0.379×10^{-3}	1.81×10^{-3}	8.31×10^{-3}
Iso. Exponent	0.970	0.970	0.970
Kin. Hard. (MPa ^{A6+1})	0.0		
Kin. Recov. (1/MPa-sec)	0.0		
Kin. Exponent	0.0		
Flow Stress - D ₀ (MPa)	8.2759		
Damage Param. - a	1.31636		
Damage Param. - b	1.96078		
Damage Param. - c	0.250		

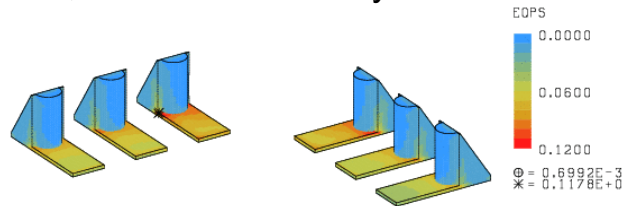
Table 3. Parameters for orthotropic elastic board.

Parameter	Value
Young's Modulus XX, ZZ (MPa)	22,069
Young's Modulus YY (MPa)	5,517
Poisson's Ratio YX	0.0234
Poisson's Ratio ZX	0.150
Poisson's Ratio ZY	0.380
Shear Modulus XY (MPa)	5,545
Shear Modulus YZ (MPa)	5,545
Shear Modulus ZX (MPa)	9,593
Thermal Exp. Coefficient XX,ZZ (1/°C)	17.0×10^{-6}
Thermal Exp. Coefficient YY (1/°C)	55.0×10^{-6}

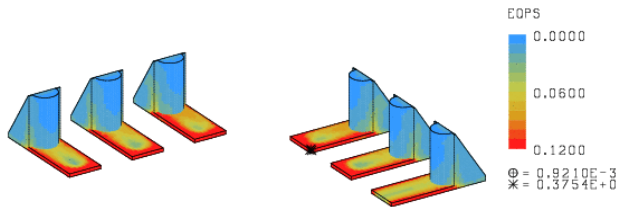
LCC24 Results



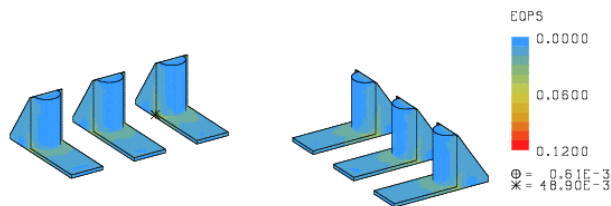
(a) no coat, no underfill 190 cycles to start crack



(b) 0.127 mm coat over, 114 cycles to start crack

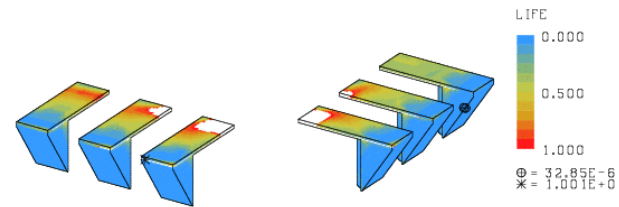


(c) 5 mil cc with cc flow under, 12 cycles to start crack

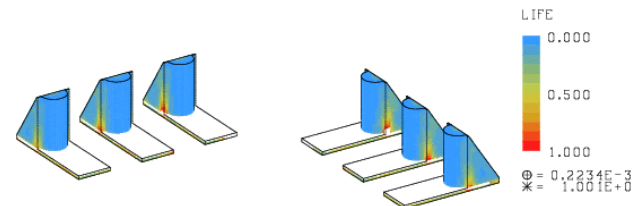


(d) 5 mil cc with underfill, 637 cycles to start crack

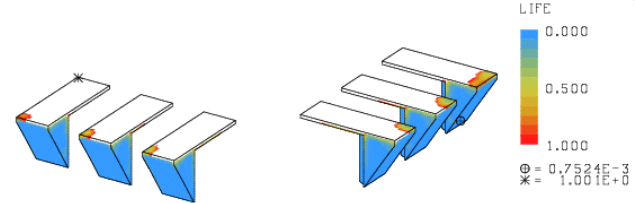
Predicted solder $\Delta EQPS$ for 24 I/O LCC



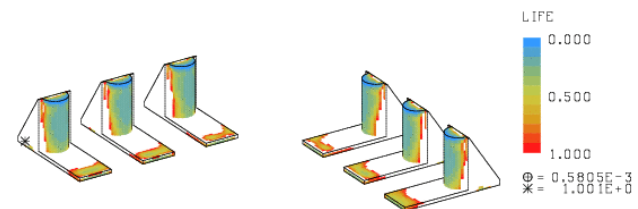
(a) no coat, no underfill, crack extent at **1020 cycles**



(b) 0.127 mm coat over, crack extent at **570 cycles**



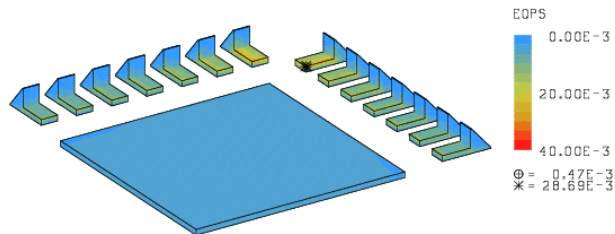
(c) 5 mil cc with cc flow under, crack extent at **270 cycles**



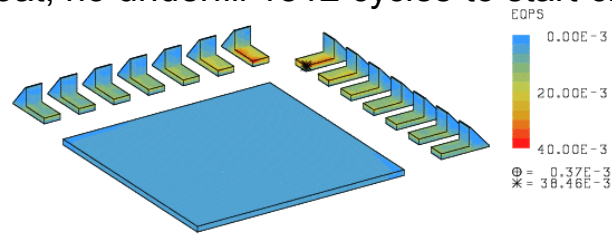
(d) 5 mil cc with underfill, crack extent at **4000 cycles**

Predicted LCC24 crack extent

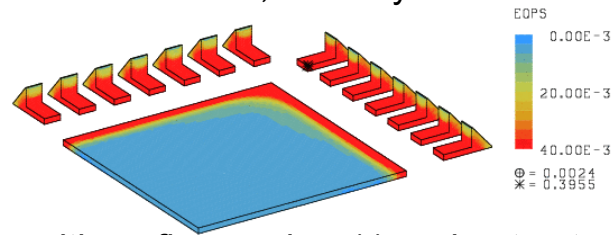
QFN56 Results



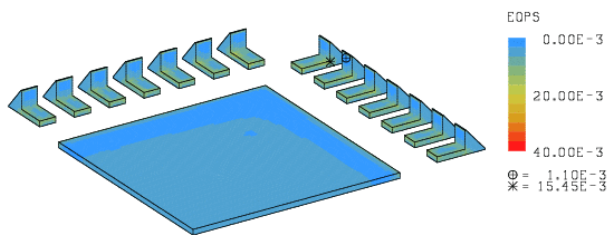
(a) no coat, no underfill 1812 cycles to start crack



(b) 0.127 mm coat over, 1020 cycles to start crack

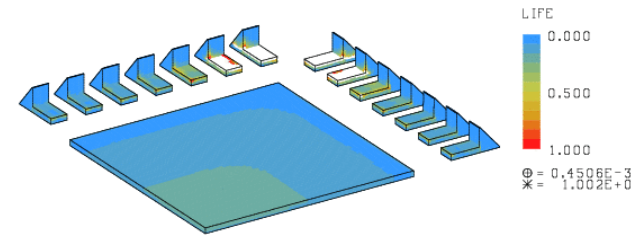


(c) 5 mil cc with cc flow under, 11 cycles to start crack

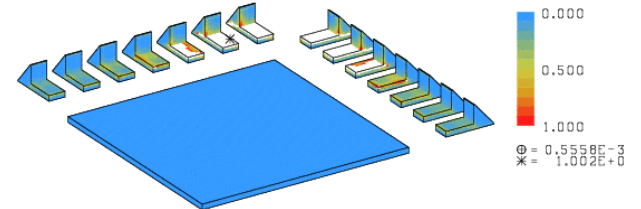


(d) 5 mil cc with underfill, 6098 cycles to start crack

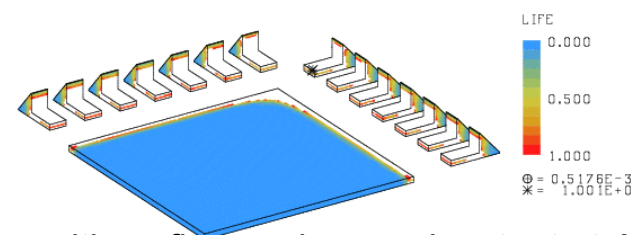
Predicted solder Δ EQPS for 56 I/O QFN



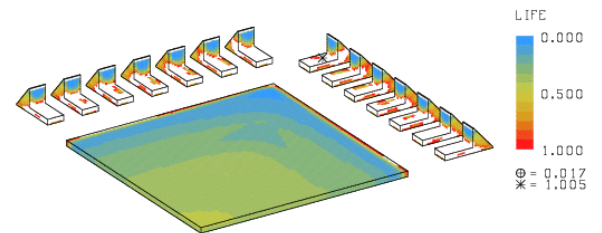
(a) no coat, no underfill, crack extent at **7,750 cycles**



(b) 0.127 mm coat over, crack extent at **3,750 cycles**



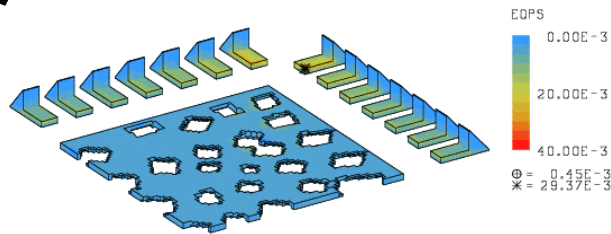
(c) 5 mil cc with cc flow under, crack extent at **160 cycles**



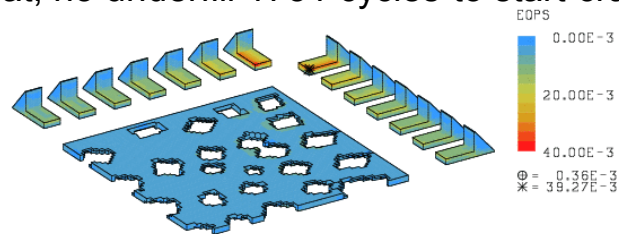
(d) 5 mil cc with underfill, crack extent at **19,000 cycles**

Predicted QFN crack extent

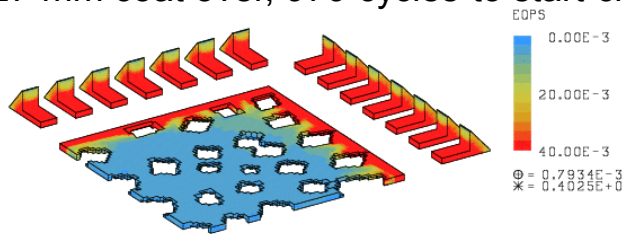
QFN56 with 30% Voids Results



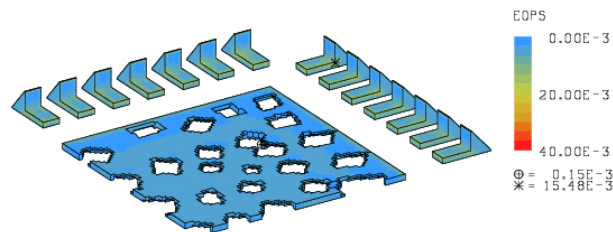
(a) no coat, no underfill 1731 cycles to start crack



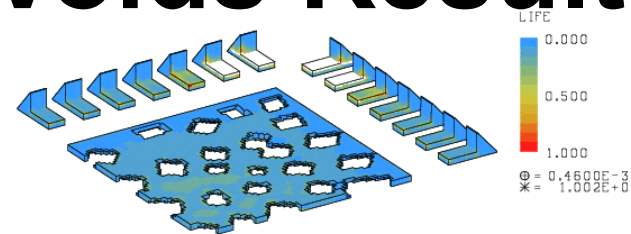
(b) 0.127 mm coat over, 979 cycles to start crack



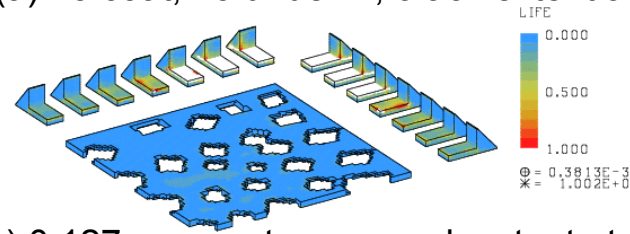
(c) 5 mil cc with cc flow under, 10 cycles to start crack



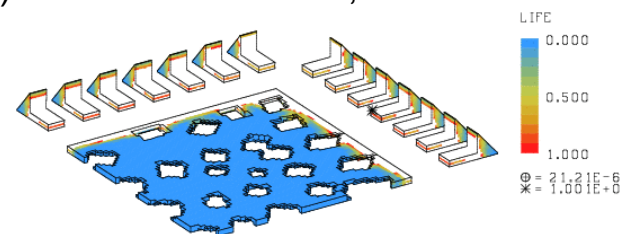
(d) 5 mil cc with underfill, 6075 cycles to start crack



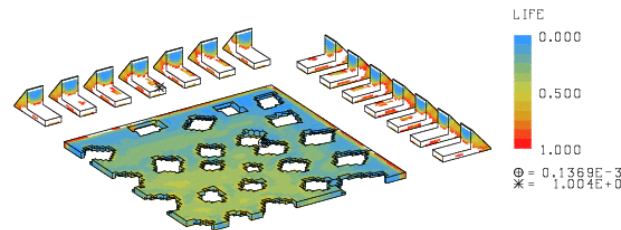
(a) no coat, no underfill, crack extent at 7,750 cycles



(b) 0.127 mm coat over, crack extent at 3,750 cycles

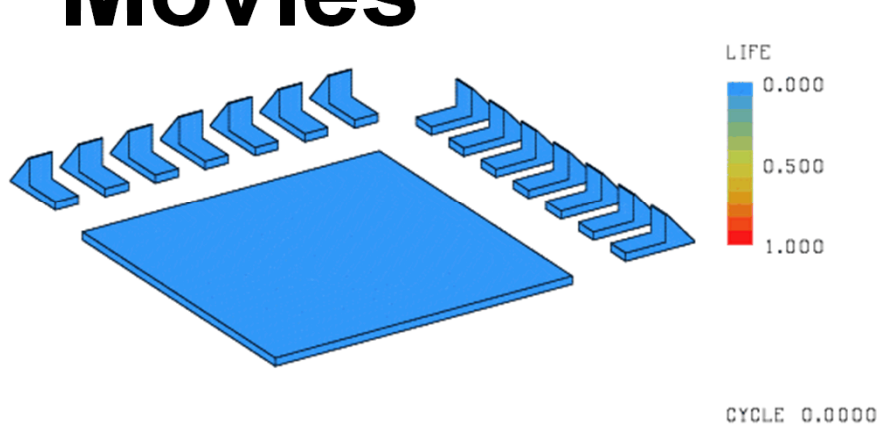


(c) 5 mil cc with cc flow under, crack extent at 160 cycles

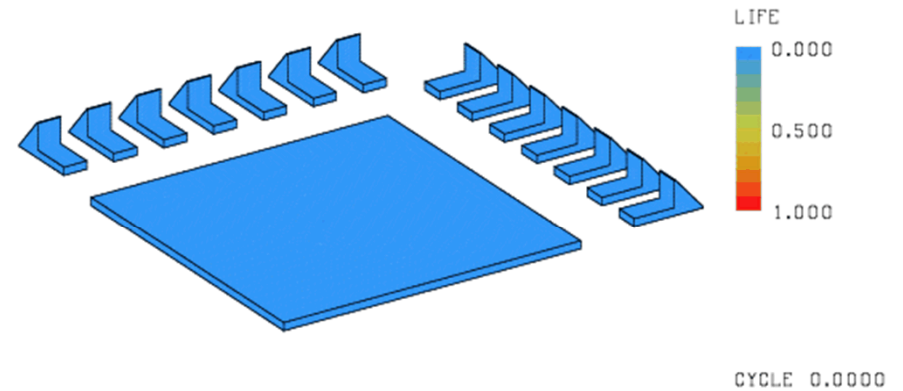
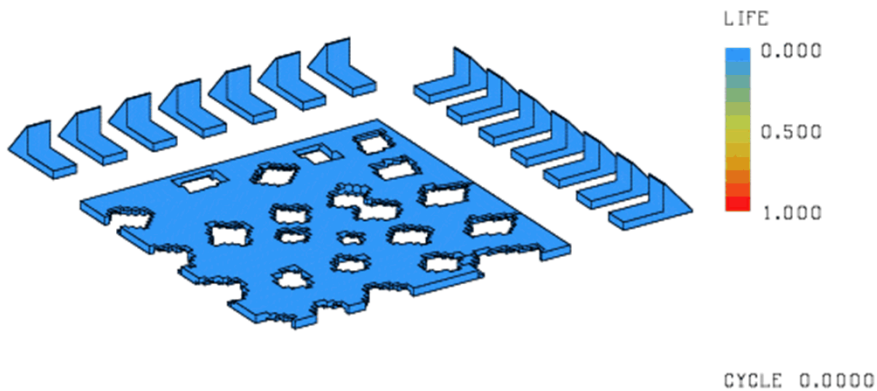


(d) 5 mil cc with underfill, crack extent at 19,000 cycles

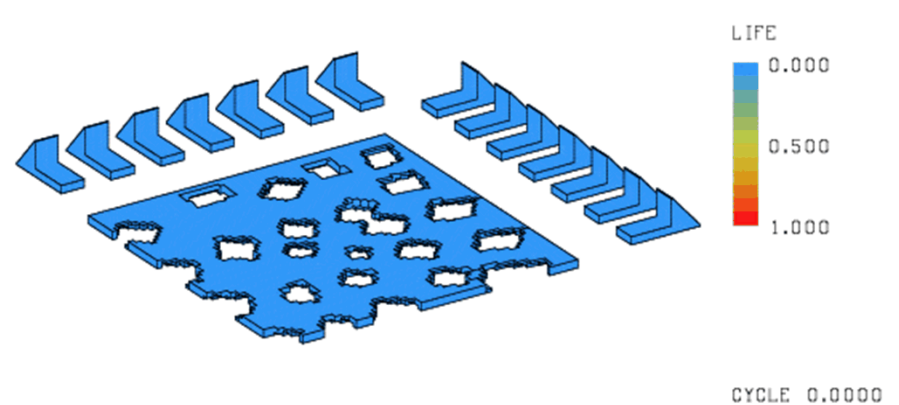
Movies



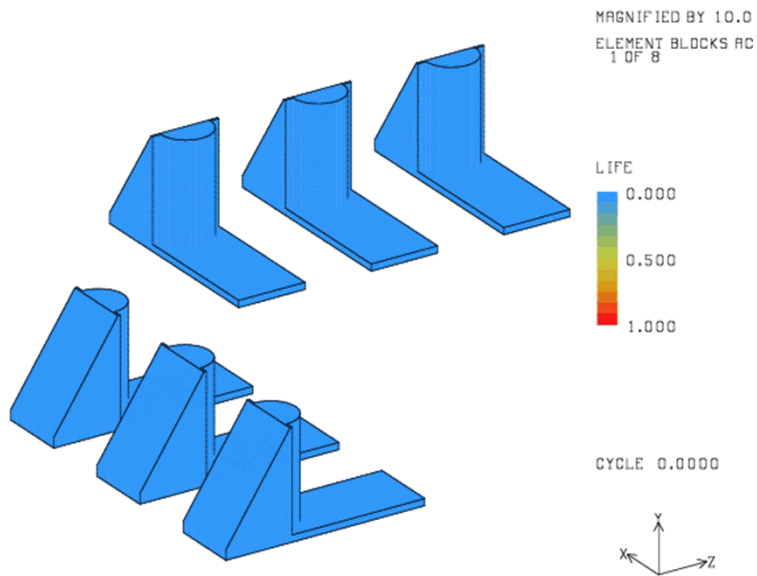
QFN56_Free
(displacements x 10)



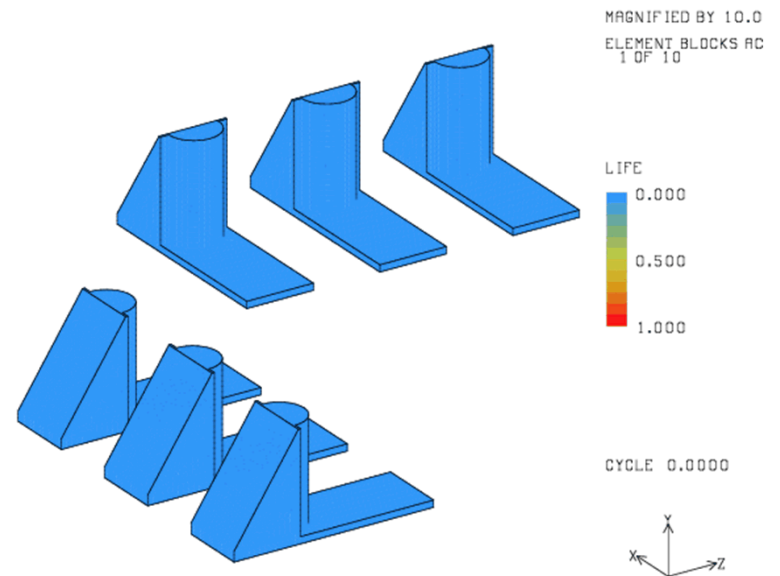
QFN56_CC_under
(displacements x 10)



Movies



LCC24_Free
(displacements x 10)



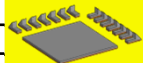
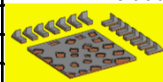
LCC24_CC_under
(displacements x 10)

Summary

Results from this numerical study indicated that:

1. The 24 I/O LCC generally has a much shorter thermal mechanical fatigue life than the 56 I/O QFN because it has a ceramic package which creates more thermal expansion mismatch with the board.
2. Allowing the conformal coat to fill the gap under these packages dramatically reduces thermal mechanical fatigue life and should be avoided if possible.
3. Use of underfill prevents conformal coat from getting under the component and also significantly increases the predicted thermal mechanical fatigue life of the solder interconnects.
4. Significant voiding in solder for the QFN's large thermal pad had little effect on predicted lifetime.

Table 4. Predicted cycles to fatigue crack start and open.

Model	$\Delta EQPS$	Cycles to Start Crack	Cycles to Electrical Open
LCC24			
lcc24 free	0.090650	189.9	1020
lcc24 cc	0.117800	113.6	570
lcc24 cc under	0.375400	11.7	270
lcc24 ufill	0.048900	636.9	4000
QFN56			
qfn56 free	0.028690	1811.8	7750
qfn56 cc	0.038460	1019.9	3750
qfn56 cc under	0.395500	10.6	160
qfn56 ufill	0.015450	6097.9	19000
QFN56 voids			
qfn56 free	0.029370	1730.5	7750
qfn56 cc	0.039270	979.0	3750
qfn56 cc under	0.402500	10.2	160
qfn56 ufill	0.015480	6074.7	19000



Thank You!

Experimental measurements of Young's modulus for the conformal coat and underfill by **Dr. Edward M. Russick**, Sandia National Laboratories, were most helpful.

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