From Chapter 3, "Reliability of leaded assemblies", SMT Reliability Manual (manuscript in progress)
Author: J-P. Clech, EPSI Inc., January 6, 1999; tel: (973)746-3796, e-mail: jpclech@aol.com

3.7 Fine-Pitch PQFP Assembly Reliability

3.7.1 0.4 mm Pitch, 256 I/O PQFP Test Vehicles

Plastic Quad Flat Pack (PQFP) packages have tall, compliant leads. Under thermal cycling conditions, infant mortality failures of PQFP assemblies are attributed, in general, to insufficient solder volume due to mis-printing of solder paste. Solder joint wear-out failures for properly assembled PQFPs occur much later, typically past 10,000 cycles under commercial ATC conditions, 0 to 100ºC with 5+ minute dwells at the temperature extremes. Since PQFPs have very compliant leads, with a diagonal stiffness K_D of the order of 5-10 lb/in, wear-out failures are driven by local CTE mismatches between solder, the lead foot and the mounting substrate.

Assembly reliability studies for commonly used fine-pitch PQFPs have been conducted and documented in detail by Lau et al. (1993/94), Lau & Pao (1997), Yeo et al. (1996) and many others. Results of the Lau and Yeo studies are highlighted hereafter. Both addressed the reliability of 0.4 mm pitch, 256 I/O PQFPs with a copper leadframe. Design parameters and thermal conditions that were used for reliability modeling of both types of test vehicles and test conditions are given in Appendix E including geometry input for lead stiffness calculations.

Source	Lau et al., 1994	Yeo et al., 1996
Pad size	1.26 mm x 0.2 mm	1.8 mm x 0 .2 mm
Paste height	4.25 mil to 8.14 mil	5.97 mil, std. deviation: < 0.6 mil
Thermal Conditions	-40ºC /125ºC , 45 min. cycle	-55ºC /125ºC , 50 min. cycle

Table 3.10: Main differences in comparative study of 0.4 mm pitch, 256 I/O PQFP reliability tests.

Components in the two independent experiments were similar with only slight differences in lead geometry. Nominal lead parameters of Lau's PQFPs were 0.5 mm foot length (19.7 mil), 0.15 mm (5.9 mil) width and 0.127 mm (5 mil) lead thickness. Assembly parameters and thermal conditions were somewhat different, as indicated in Table 3.10. Mounting pads were nominally wider than the lead foot: 0.2 mm (7.87 mil) versus 0.15 mm (5.90 mil). This pad design provides for side fillets that are beneficial to solder joint reliability. The reader is referred to the original papers by Lau et al.(1993/94) and Yeo et al. (1996) for complete details on the design-of-experiments, assembly of test vehicles and test procedures.

Cracks in PQFP solder joints typically initiate at the toe and/or heel fillet and propagate through solder close to the lead foot. Because of a possible lack of solder wettability at the lead tip, toe fillets with a reduced height lead to higher solder joint stresses that diminish both the crack initiation and the crack propagation time. Tall heel fillets enhance reliability since they provide for a longer crack propagation path. For comparison purposes, Lau et al. reported an average heel fillet thickness (or height) of 0.067 mm (2.637 ± 0.171 mil) for solvent-clean assemblies and 0.0725 mm (2.856 ± 0.249 mil) for no-clean assemblies. Yeo et al. reported fillets that were 250 μm (9.84 mil) in the heel area. and toe fillets that were 80 μm (3.15 mil) tall.

3.7.2 256 I/O PQFP Failure Statistics

The raw failure data are plotted on two-parameter (2P) Weibull paper in Figure 3.22. The plot was generated with the WeibullSmith™ software from Fulton Findings, Inc. The legend at the bottom right gives characteristic lives ("eta"), the slopes of failure distributions ("beta"), the "goodness of fit" correlation coefficients ("r^2"), sample size ("n") and the number of suspensions ("s"), that is the number of components that did not fail when the test was terminated. Note that for Yeo's dataset, we use a sample size of 42 whereas the original paper quoted a sample size of 48. We used a reduced sample size to account for the fact that 6 samples were suspended at 1000 cycles intervals for microstructural analysis. We believe that this may have had an impact on the statistical analysis in the original publication by Yeo et al. since the authors obtained a three-parameter (3P) Weibull slope β that was less than 1. That slope has to be larger than 1 for failure rates to increase over time as is expected with wear-out of solder joints.

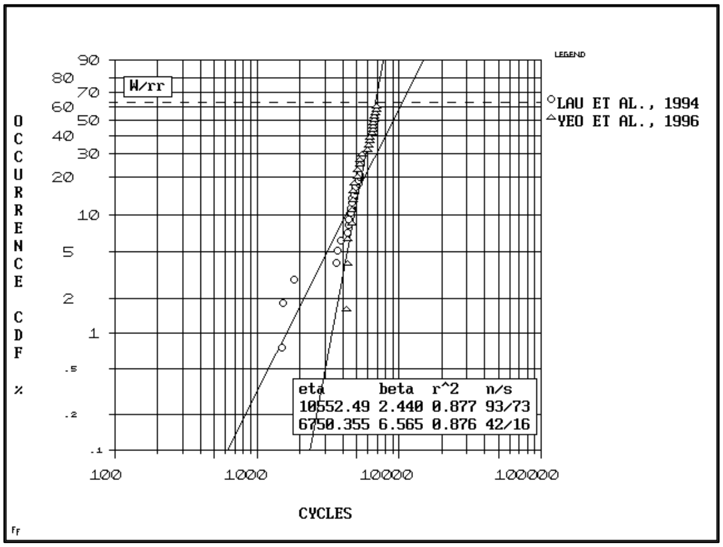


Figure 3.22: 2P Weibull plot of PQFP failures. Raw data is from thermal cycling experiments by Lau et al. (1994) and Yeo et al. (1996)

Lau's failure distribution shows that three "early" failures occurred in the range 1000 to 2000 cycles. The following failure occurred at about 3500 cycles. It is not clear what the cause of these "early" failures is. However, because of the apparent gap in the failure distribution, we treat the "early" failures as outliers and remove them from the failure population. Following this adjustment, the data is re-plotted on 2P Weibull paper (see Figure 3.23).

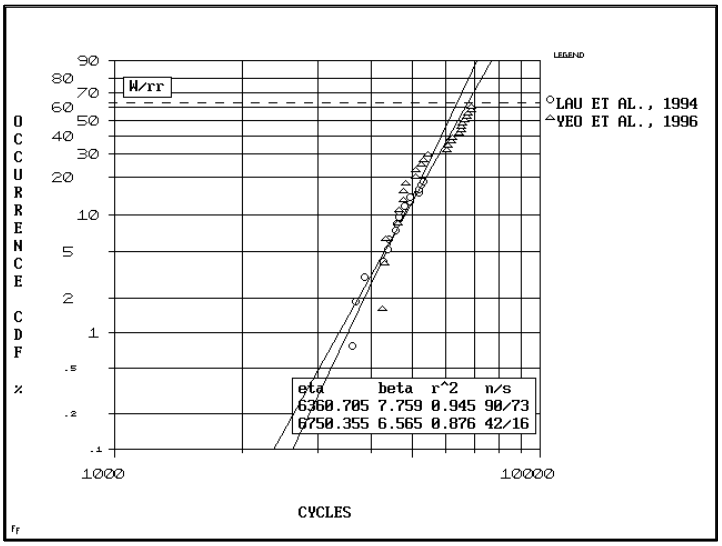


Figure 3.23: 2P Weibull plot of PQFP failure distributions after removal of outliers. Failure data is from thermal cycling experiments by Lau et al. (1994) and Yeo et al. (1996)

Even though the -55/125ºC cycle is slightly more damaging than the -40/125ºC test, the failure distributions in Figure 3.23 almost overlap. The moderately high values of 2P Weibull shape parameters (β = 7.7 and 6.5) indicate that the quality of solder joints is rather homogeneous across the populations of joints under test. The failure distributions in Figure 3.23 also show some curvature, suggesting that 3P Weibull statistics with failure-free cycles may be more appropriate (see Chapter 4 for more information on failure statistics and Weibull distributions). The data was re-analyzed using the 3P Weibull option of the WeibullSmith™ software. The output parameters are given in Table 3.11.

	3P Weibull Parameters			
Dataset	Failure-Free Time N_0 (cycles)	Characteristic Life α (cycles)	Slope β	Correlation Coefficient r^2
Lau et al. (1994)	3050	7714	2.184	0.961
Yeo et al. (1996)	4184	7762	1.017	0.97

Table 3.11: 3P Weibull parameters of 256 I/O PQFP failure data.

The two datasets have similar characteristic lives. The slopes β are greater than 1 which, as expected, is indicative of failure rates increasing over time. Although Yeo et al.'s test had a larger temperature swing, the data yields a failure-free time that is 37% larger than in Lau's test. One possible explanation of this effect is the higher heel fillets in Yeo et al.'s test vehicles.

3.7.3 PQFP Reliability Modeling

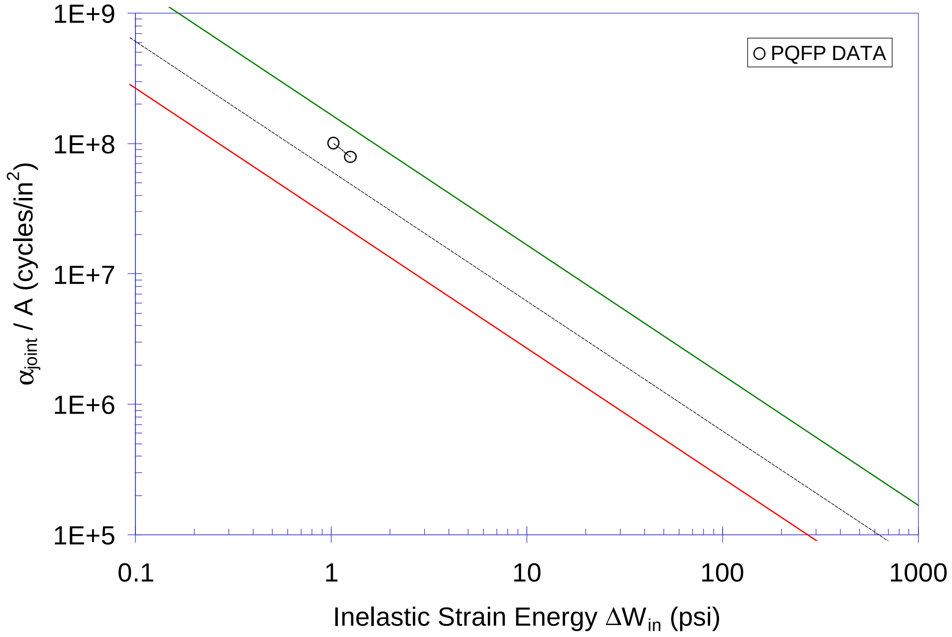


Figure 3.24: Fit of PQFP accelerated test data to the SRS correlation band.

Figure 3.24 shows the fit of the above PQFP data to the SRS correlation band. Input data for the two types of test vehicles and test conditions is listed in Appendix E. Cyclic strain energy, computed with the SRS software, was dominated by local CTE mismatch effects. The test results fit the model nicely. More interestingly, a trendline through the two data points is almost parallel to the centerline of the SRS correlation band. This parallelism suggests that the results of the two experiments are consistent with each other and that acceleration between the two conditions is linear.

References

Lau, J., Pao, Y.-H., Larner, C., Govila, R., Twerefour, S., Gilbert, D., Erasmus, S. and Dolot, R., "Reliability of 0.4 mm pitch, 256-pin Plastic Quad Flat Pack no-clean and water-clean solder joints", Proceedings, 43rd Electronic Components and Technology Conference, Orlando, FL, June 1-4, 1993, pp. 858-862.

Lau, J. H., Pao, Y-H., Larner, C., Twerefour, S., Govila, R., Gilbert, D., Erasmus, S. and Dolot, S., “Reliability of 0.4 mm pitch, 256 pin Plastic Quad Flat Pack no-clean and water-clean solder joints”, Soldering and Surface Mount Technology, No. 16, February 1994, pp. 42-50. Also in *Solder Joint Reliability of BGA, CSP, Flip Chip and Fine Pitch SMT Assemblies*, J. H. Lau and Y-H. Pao, McGraw-Hill, 1997, Chapter 8, pp. 356-370.

Yeo, C. K., Mhaisalkar, S. and Pang, H. L. J., “Experimental study of solder joint reliability in a 256 pin, 0.4 mm pitch PQFP”, *Journal of Electronics Manufacturing*, Vol. 6, No. 2, June 1996, pp. 67-78.

Appendix E: Input Data for PQFP Reliability Analysis

LAU ET AL.'S TEST

INPUT OF SOLDER RELIABILITY SOLUTIONS PROGRAM

PROJECT

Title: 256 I/O PQFP / Cu leads / Lau's test   Notes:

COMPONENT DATA

Name: 256 I/O PQFP

Number of susceptible IOs: 256

Global Mismatch Parameters:

Distance to Neutral Point, DNP: 8.018E-01 inch

Effective CTE: 2.200E-05 /deg.C

Local Mismatch Parameters:

Thickness of lead or component at solder joint: 5.000E-03 inch

Effective CTE of lead or component at solder joint: 1.700E-05 /deg.C

Effective Young's modulus of lead or component at solder joint: 1.750E07 psi

SUBSTRATE DATA

Substrate material: FR-4

Effective in-plane CTE in diagonal direction of component: 1.500E-05 /deg.C

Young's modulus in tension: 1.600E06 psi

Thickness: 6.200E-02 inch

ASSEMBLY DATA

Assembly stiffness: 4.940E00 lb/in

Solder joint effective thickness: 3.500E-03 inch

Solder joint crack area: 1.650E-04 sq.inch

THERMAL CONDITIONS

Number	Temperature C	Dwell min.	Cycles	Name

	Hot	Cold	Hot	Cold		
1	125.0	-40.0	20.0	4.0	32.000 CPD	Accelerated test

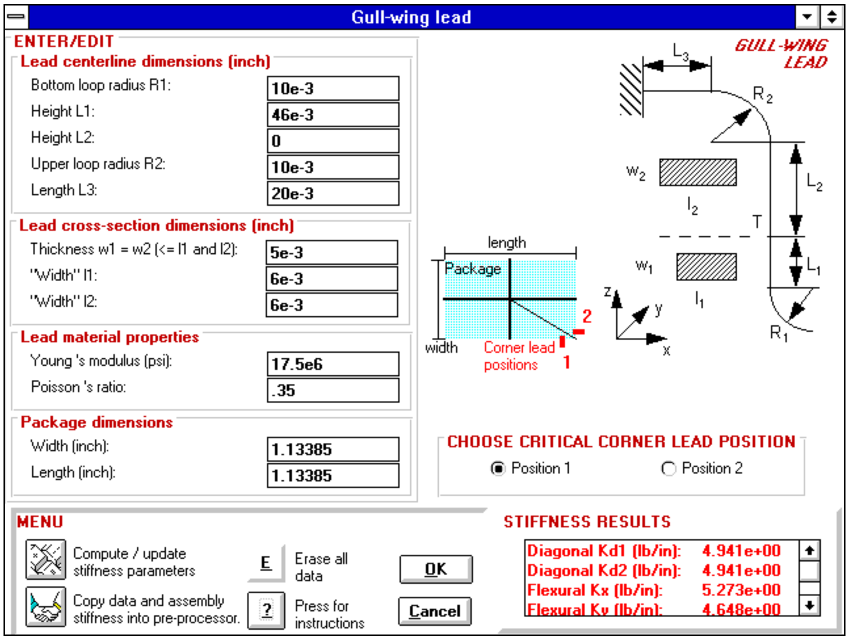
Note: F = Fixed cycles; CPD = Cycles Per Day for variable type cycles

DESIGN LIFE and STATISTICAL PARAMETERS

Product design life: 5.000 Years

2P Weibull shape parameter (beta): 7.759

3P Weibull ratio: failure free time / characteristic life: 0.395



ENTER/EDIT

Lead centerline dimensions (inch)

Bottom loop radius R1: 10e-3
Height L1: 46e-3
Height L2: 0
Upper loop radius R2: 10e-3
Length L3: 20e-3

Lead cross-section dimensions (inch)

Thickness w1 = w2 (<= l1 and l2): 5e-3
"Width" l1: 6e-3
"Width" l2: 6e-3

Lead material properties

Young 's modulus (psi): 17.5e6
Poisson 's ratio: .35

Package dimensions

Width (inch): 1.13385
Length (inch): 1.13385

CHOOSE CRITICAL CORNER LEAD POSITION

● Position 1 ○ Position 2

STIFFNESS RESULTS

Diagonal Kd1 (lb/in): 4.941e+00
Diagonal Kd2 (lb/in): 4.941e+00
Flexural Kx (lb/in): 5.273e+00
Flexural Ky (lb/in): 4.648e+00

Figure E.1: SRS input window for lead stiffness calculations: Lau et al.'s test vehicle.

YEO ET AL.'S TEST

INPUT OF SOLDER RELIABILITY SOLUTIONS PROGRAM

PROJECT

Title: 256 I/O PQFP / Cu leads / Yeo's test Notes:

COMPONENT DATA

Name: 256 I/O PQFP

Number of susceptible IOs: 256

Global Mismatch Parameters:

Distance to Neutral Point, DNP: 8.018E-01 inch

Effective CTE: 2.200E-05 /deg.C

Local Mismatch Parameters:

Thickness of lead or component at solder joint: 6.000E-03 inch

Effective CTE of lead or component at solder joint: 1.700E-05 /deg.C

Effective Young's modulus of lead or component at solder joint: 1.750E07 psi

SUBSTRATE DATA

Substrate material: FR-4

Effective in-plane CTE in diagonal direction of component: 1.800E-05 /deg.C

Young's modulus in tension: 1.600E06 psi

Thickness: 6.300E-02 inch

ASSEMBLY DATA

Assembly stiffness: 6.055E00 lb/in

Solder joint effective thickness: 3.000E-03 inch

Solder joint crack area: 1.570E-04 sq.inch

THERMAL CONDITIONS

Number	Temperature C		Dwell min.		Cycles	Name
	Hot	Cold	Hot	Cold		
1	125.0	-55.0	10.0	10.0	28.800 CPD	Acc. test

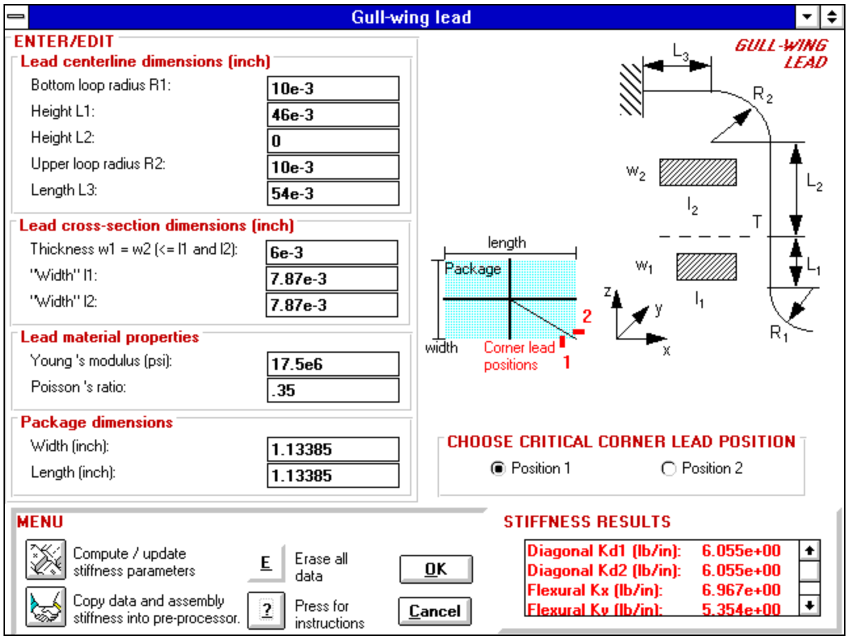
Note: F = Fixed cycles; CPD = Cycles Per Day for variable type cycles

DESIGN LIFE and STATISTICAL PARAMETERS

Product design life: 5.000 Years

2P Weibull shape parameter (beta): 6.565

3P Weibull ratio: failure free time / characteristic life: 0.539



Lead centerline dimensions (inch)

Bottom loop radius R1: 10e-3

Height L1: 46e-3

Height L2: 0

Upper loop radius R2: 10e-3

Length L3: 54e-3

Lead cross-section dimensions (inch)

Thickness w1 = w2 (<= l1 and l2): 6e-3

"Width" l1: 7.87e-3

"Width" l2: 7.87e-3

Lead material properties

Young 's modulus (psi): 17.5e6

Poisson 's ratio: .35

Package dimensions

Width (inch): 1.13385

Length (inch): 1.13385

CHOOSE CRITICAL CORNER LEAD POSITION

● Position 1 ○ Position 2

STIFFNESS RESULTS

Diagonal Kd1 (lb/in): 6.055e+00

Diagonal Kd2 (lb/in): 6.055e+00

Flexural Kx (lb/in): 6.967e+00

Flexural Ky (lb/in): 5.354e+00

Figure E.2: SRS input window for lead stiffness calculations: Yeo et al.'s test vehicle.