<u>**COMPARISON OF CBGA AND LCCC FAILURE DATA AND LIFE PREDICTIONS**</u>

This document is part of a paper given at Nepcon West'99: Reichelt, G. and Clech, J-P., "Life expectancy of solder joints SMD-PCB: comparing test data to an improved life prediction equation", Proceedings, Nepcon West '99, Anaheim, CA, February 21-25, 1999, Vol. III, pp. 1269-1285.

# 1. CBGA Life Predictions

## *1.1 Test Results and Life Prediction Summary*

This section compares life predictions and test results for the 256 I/O, 1.27 mm pitch Ceramic Ball Grid Array (CBGA) assemblies of the "German Joint Project" [1, 2]. CBGAs mounted on FR-4 were thermally cycled under two conditions: "L" ("langsame" or slow) and "S" ("schnelle" or rapid). Thermal conditions and the resulting characteristic lives are given in Table 1 below. Packages were 19.05 mm square.

| Thermal Condition | Cold Temperature / Dwell Time | Hot Temperature / Dwell Time | Characteristic Life | | Figure and page number in [1] |
|---|---|---|---|---|---|
| | | | Test | Predictions | |
| "L" | -20ºC, 15 minutes | 100ºC, 30 minutes | 890 cycles | 970 cycles | 3.8.1/24, page 17 |
| "S" | -55ºC, 30 minutes | 125ºC, 30 minutes | 640 cycles | 753 cycles | 3.8.1/43, page 25 |

**Table 1:** Thermal cycling conditions, characteristic lives in test ans SRS model predictions.

Test vehicles for condition "L" had 200µm paste thickness and a post-reflow, average standoff height of 0.85 mm (33.5 mil). The boards that were tested under condition "S" had 300 µm paste and an average standoff height of 0.9 mm (35.4 mil). Characteristic lives in test were read off plots of Weibull failure distributions given in [1]. Life predictions were obtained with the Solder Reliability Solutions (SRS) software [3, 4]. Background information and details of the CBGA reliability analysis are given in the following sub-sections. As seen in Table 1, life predictions based on the centerline of the SRS model correlation are 9% to 18% above the test results.

## *1.2 SRS Model Background*

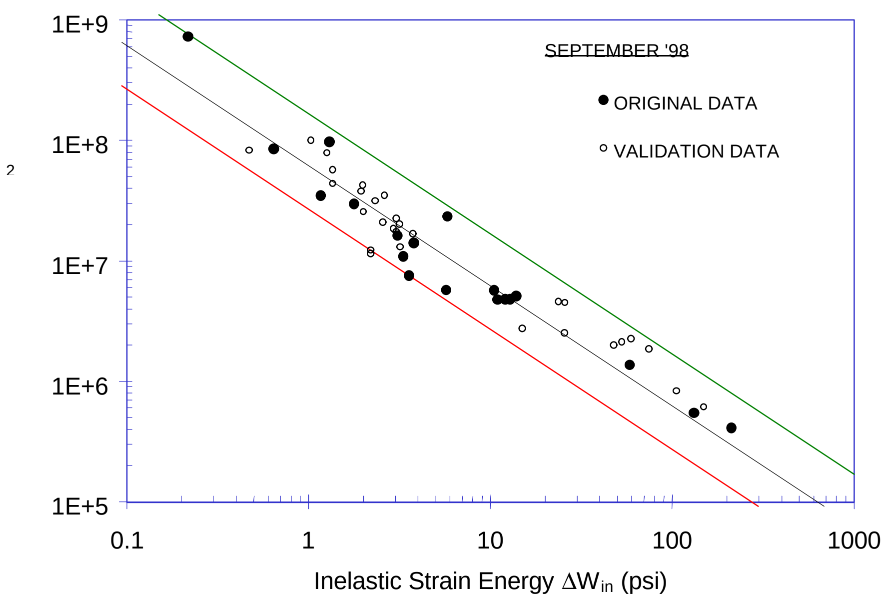


**Figure 1:** SRS model correlation of SMT solder joint fatigue data.

The SRS model uses a strain energy based fatigue law that was developed by correlating SMT fatigue data from 19 experiments. The original correlation, with a slope of -1, was frozen as shown in Figure 1. The horizontal axis is the cyclic inelastic strain energy, $\Delta W_{in}$, that is imparted to the solder joints and the vertical axis is the solder joint characteristic life, $\alpha_{joint}$, scaled for the solder cracked area, A. Inelastic strain energy is obtained as the area of solder joint stress/strain loops during thermal cycling. The solder constitutive model includes temperature-dependent creep and plastic flow. The original correlation is based on 19 datasets shown as solid circles in Figure 1. About 30 data points were added to the plot as part of an on-going process of checking the model validity when new test results and related design parameters become available. The validation data is shown as hollow circles in Figure 1. The spread of the data around the model centerline is a factor 2.3 - 2.7 X, which is typical of fatigue correlations. More details on the mechanics of the SRS model are given in [3, 4].

## *1.3 CBGA Modeling / Discussion*

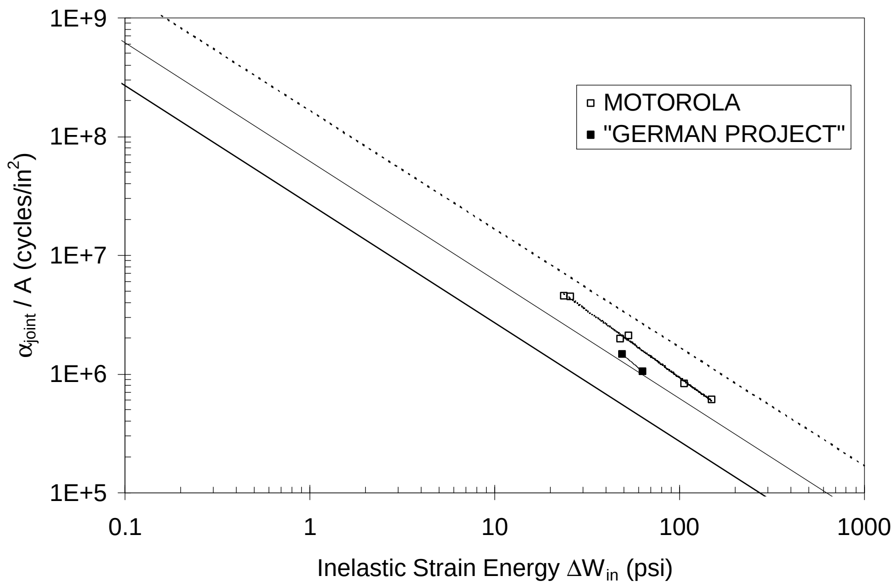


**Figure 2:** Fit of CBGA failure data to the SRS correlation band.

The 256 I/O CBGAs had an alumina lid attached to the ceramic substrate. The alumina lid was about 25 mil thick. The CBGA substrate was 1.25 mm thick (about 50 mil). To account for stiffening of the CBGA substrate due to the presence of the lid, we modeled the CBGA component as a plate of thickness 75 mil, that is the substrate plus lid thickness. Input parameters that were used for the 256 I/O CBGA assembly with 200 µm paste are given in Appendix. The fit of the 256 I/O CBGA data to the SRS correlation band is shown in Figure 2. The two data points, shown as solid squares and labeled "German Project", are close to the model centerline. A linear trendline that was fit to the data is almost parallel to the model centerline.

Figure 2 also shows the fit of Motorola CBGA reliability data [5] to the model. Those six data points are for CBGAs of sizes 21 mm square, 21 x 25 mm and 32.5 mm square. Thermal conditions were 0 to 100ºC and -40 to 125ºC. The linear trendline that was fit through the Motorola data is almost parallel to the model centerline as well. This parallelism suggests that the model provides accurate acceleration factors and can be used with confidence to extrapolate failure data from test to use conditions, or to scale reliability data from one CBGA package size to another. The offset between the two trendlines, i.e. Motorola versus "German Project", is a factor 1.4 X, which is possibly due to design and manufacturing differences, process and material variability, as well as possible differences in failure criteria and the failure event detection systems. Motorola authors [5] also reported that their CBGA database showed an increase in reliability over previous generation CBGA assemblies. Reliability went up by as much as 2.7 X in the last three years, which was attributed to "improvements in process and material quality".

## 2. LCCC Assembly Reliability

### 2.1 Test Vehicles / Accelerated Test Data

The "German Project" test vehicles included 20 I/O and 84 I/O castellated Leadless Ceramic Chip Carriers (LCCCs) on FR-4 [6]. While the test matrix covered LCCCs assembled with intentional offsets (x-, y-, x & y, and rotational offsets), this initial modeling work only addresses LCCC assemblies without placement offsets. In future work, we will attempt to include and quantify the effect of placement offsets on LCCC attachment reliability.

| | α (cycles) / slope β | |
|---|---|---|
| Paste thickness | 100 μm | 200 μm |
| 20 I/O LCCC | 737 / 6.14 | 885 / na |
| 84 I/O LCCC | 90 / 2.23 | 145 / 2.85 |

*na = 2P Weibull slope "not available"

**Table 2:** Test results for 20 and 28 I/O LCCC assemblies (no offset) subject to slow thermal cycling ("L").

Characteristic lives (α) and two-parameter Weibull slopes (β) for LCCC assemblies subject to slow thermal cycling conditions ("L": -20 to 100ºC) are given in Table 2. Paste thickness was 100 μm or 200 μm. In both cases, the post-reflow thickness of the solder layer under the LCCC termination was an average of 0.065 mm (2.56 mil).

### 2.2 LCCC Life Predictions / Discussion

The "100 μm" LCCCs had no distinctive toe fillet running up the castellations. Their solder joints were modeled as thin solder layers in shear. The "200 μm" LCCCs had small toe fillets running up the castellations. For those assemblies, life predictions were made by running the SRS model twice, adding cycles for crack propagation in the thin solder layer under the termination and cycles for crack propagation at an angle of 30 to 45º through the toe fillet. The application of this empirical technique, due to Wen et al. [7, 8], was described and validated in [3] using test results of the NASA-JPL (Jet Propulsion Laboratory) accelerated test program. All parameters needed for modeling the LCCC assemblies (dimensions, material properties, solder joint cross-sections) were available in the LCCC manual of the "German Project" Kompendium [6].

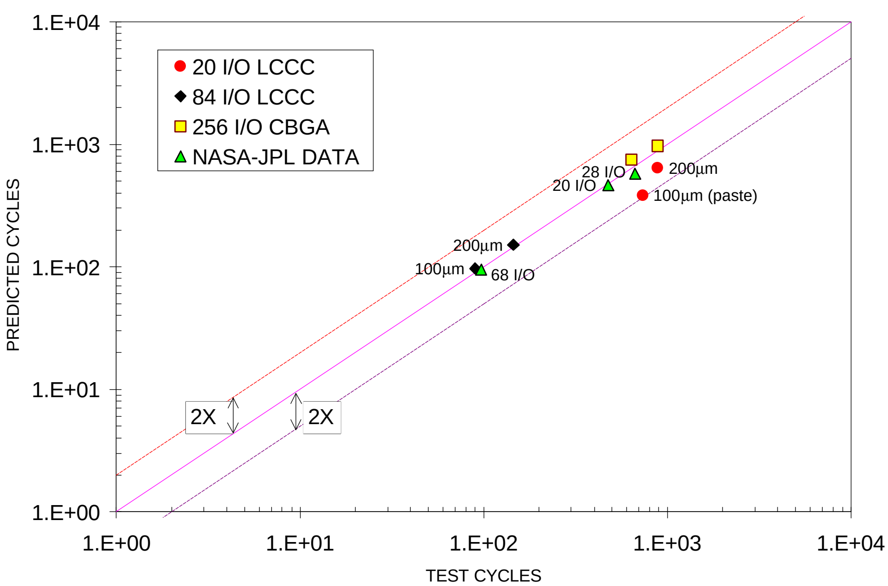


**Figure 3:** LCCC life predictions versus test results. Cycles-to-failure are characteristic lives of 2P Weibull failure distributions. Paste thickness is indicated for the 20 and 84 LCCCs of the German Project.

Because we ran the SRS model twice for LCCC assemblies with 200 μm paste, we cannot plot the "200 μm" LCCC test data directly on the SRS correlation plot. Instead, results are presented as predicted cycles-to-failure versus cycles-to-failure in test, as shown in Figure 3. Data points that fall on the main diagonal of Figure 3 are a perfect match between life predictions and test results. From Figure 3, the 20 I/O LCCCs life predictions (shown as circles) are a factor 1.4 to 1.9 X below the test results. Life predictions for the 84 I/O LCCCs (shown as diamonds) are 10% off the test results. The spread of the data is typical of fatigue and is a reflection of variability due to material and assembly parameters not captured in the model.

Additional data is shown in Figure 3 to put the above LCCC results in perspective. The 256 I/O CBGA results (shown as squares) under both conditions "L" and "S" have longer lives than both the 20 and 28 I/O LCCCs of the German Project. LCCC data from the NASA-JPL test program are shown as triangles, with labels indicating their respective numbers of I/Os (20, 28 and 68 I/Os). Although test conditions were somewhat different (-55 to 100ºC at 6 cycles/day versus -20 to 100ºC for condition "L") and toe fillets were thicker, the 20 and 28 I/O LCCC data from NASA-JPL test fall in the same general region of Figure 3 as the 20 I/O LCCC data of the German Project. The 68 I/O LCCC data point from NASA-JPL is in the same general area as, but below the 84 I/O LCCC from the German Project because of the larger temperature swing of the JPL test (155ºC versus 120ºC for condition "L") and differences in fillet sizes.

## Conclusions

- The Kompendium of the German SMT Reliability Project contains a wealth of data that is useful for model validation. The Kompendium also provides guidelines to assess the impact of placement offsets on attachment reliability. However, this important aspect of SMT reliability modeling was not addressed in this study.
- We tested the applicability of the SRS model versus the Kompendium thermal cycling results for CBGA and LCCC assemblies. The model captured the experimental trends correctly. We showed also that the Kompendium results and the life predictions were consistent with other industry data.
- In future work, we will extend the analysis to other leadless and leaded components and attempt to capture the effect of placement offsets on attachment reliability.

## References


[1] "German Project" Kompendium, "Zuverlässigkeit von SMT-Weichlötstellen im visuelle Grenzfallbereich", Kapitel 3.8, Bauelementform Ceramic Ball Grid Array (CBGA) und Ceramic Column Grid Array (CCGA), VDI/VDE-IT GmbH, Germany, 1996 (in German).

[2] Reichelt, G., "The German joint project "SMT-Reliability": consequences to reliability of PCB-assemblies, to SMD-footprint-design and solder joint inspection criteria", Proceedings, Nepcon West '98, Anaheim, CA, March 1-5, 1998, Vol. III, pp. 1001-1022.

[3] Clech, J-P., "Solder Reliability Solutions: a PC-based design-for-reliability tool", Proceedings, Surface Mount International Conference, Sept. 8-12, 1996, San Jose, CA, Vol. I, pp. 136-151. Also in *Soldering and Surface Mount Technology*, Wela Publications, British Isles, Vol. 9, No. 2, July 1997, pp. 45-54.

[4] Clech, J-P., "Flip-chip / CSP assembly reliability and solder volume effects", Proceedings, Surface Mount International Conference, San Jose, CA, August 25-27, 1998, pp. 315-324.

[5] Cho, Y-C. (Dennis) and Mawer, A., "Interconnect reliability of a C4/CBGA at both the chip and board level", Proceedings, Nepcon San Antonio, TX, September 3, 1996, pp. 109-118. Also in *Journal of Surface Mount Technology*, April 1998, Vol. 11, Issue 2, pp. 21-27.

[6] "German Project" Kompendium, "Zuverlässigkeit von SMT-Weichlötstellen im visuelle Grenzfallbereich", Kapitel 3.6, Bauelementform Leadless Ceramic Chip Carrier (LCCC), VDI/VDE-IT GmbH, Germany, 1996 (in German).

[7] L. C. Wen, G. R. Mon and R. G. Ross, Jr., "Reliability Assessment of Solder Joints on LCCC Packages", in *Summary of the Phase 1 Round Robin Solder Joint Life Prediction Model Results*, ed. K. Bonner and S. Cornford, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, October 28, 1994 (internal report).

[8] L. C. Wen and R. G. Ross, Jr., "Comparison of LCC solder joint life predictions with experimental data", *ASME Transactions, Journal of Electronic Packaging*, Vol. 117, No. 2, June 1995, pp. 109-115.

# <u>APPENDIX:</u> SRS Input Data for Solder Joint Reliability Analysis of 256 I/O CBGA (200 μm paste)

All required input data is listed below. Figure A.1 is a subroutine window of the SRS software that was used to estimate assembly stiffness parameters for the 256 I/O CBGA assemblies. The solder joint is shown as 33.5 mil tall for assembly with 200 μm paste and was changed to 35.4 mil for CBGA assemblies with 300 μm paste.

INPUT OF SOLDER RELIABILITY SOLUTIONS PROGRAM
SRS file name: CBGA200.SRS

PROJECT
Title: German Project CBGA (200 micron paste)
Notes: Thermal conditions here are -20 to 100C (slow cycle). For 'floor thickness" in LCCC option, we use: 75 mil = 50 mil (for ceramic substrate) + 25 mil (for thickness of lid).

COMPONENT DATA
Name: 256 I/O CBGA
Number of susceptible IOs: 4

Global Mismatch Parameters:
Distance to Neutral Point, DNP: 6.100E-01 inch
Effective CTE: 7.000E-06 /deg.C

Local Mismatch Parameters:
Thickness of lead or component at solder joint: 4.000E-02 inch
Effective CTE of lead or component at solder joint: 7.000E-06 /deg.C
Effective Young's modulus of lead or component at solder joint: 3.700E07 psi

SUBSTRATE DATA
Substrate material: FR4
Effective in-plane CTE in diagonal direction of component: 1.700E-05 /deg.C
Young's modulus in tension: 2.000E06 psi
Thickness: 6.200E-02 inch

ASSEMBLY DATA
Assembly stiffness: 8.796E03 lb/in (obtained from Figure A.1)
Solder joint effective thickness: 3.350E-02 inch
Solder joint crack area: 9.640E-04 sq.inch

THERMAL CONDITIONS

| Number | Temperature C | | Dwell min. | | Cycles | Name |
|---|---|---|---|---|---|---|
| | Hot | Cold | Hot | Cold | | |
| 1 | 100.0 | -20.0 | 30.0 | 15.0 | 24.000 CPD | Slow Cycle |

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): 6.000
3P Weibull ratio: failure free time / characteristic life: 0.500

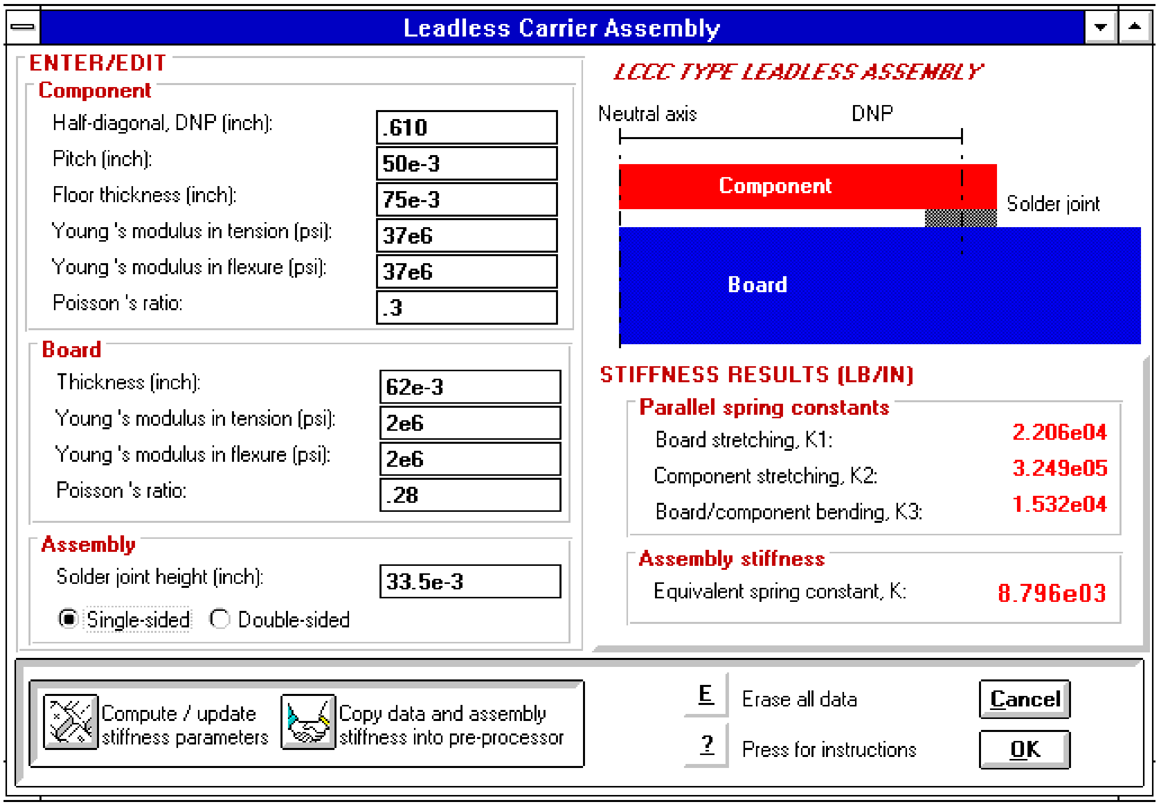


**Figure A.1:** SRS input parameters for the 256 I/O CBGA assembly stiffness calculations.