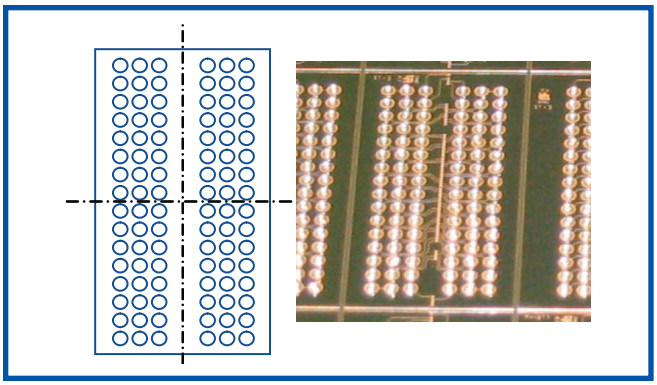

FIGURE 1: Test sample (16 x 6 WLCSP).

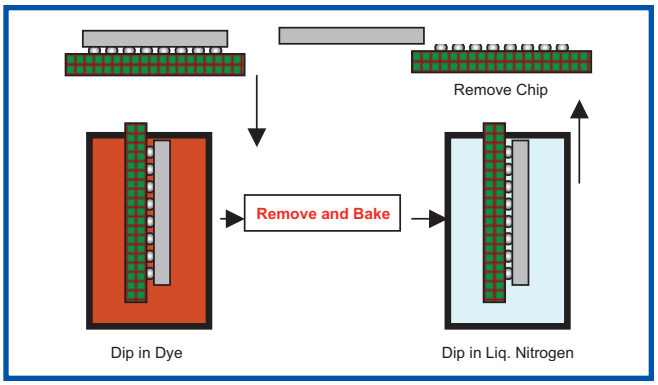

FIGURE 2: Dye penetration procedure and sample.

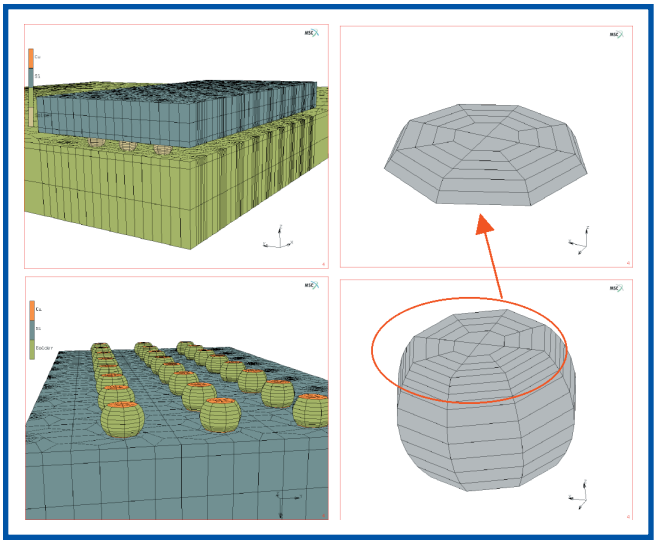

FIGURE 3: FE model – quarter symmetry.

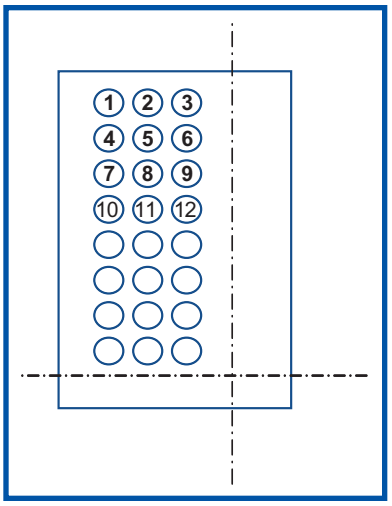

FIGURE 4: Location key for joint numbers.

Table 1. Thermal Cycle Conditions

Cycle	Ramp Up/ Down Time Setting	Measured Ramp Up/ Down Time	Dwell Time Setting	Measured Dwell Time
0° - 100°C	15 min.	9 min.	15 min.	21 min.
-40° - 125°C	15 min.	9 min.	15 min.	21 min.
-65° - 100°C	15 min.	9 min.	15 min.	21 min.

Table 2. Crack Growth Rate Data

	Crack Growth Rate (μm²/Cycle)		
Joint No.	0° - 100°C	-40° - 125°C	-65° - 100°C
1	117.4	285.3	283.5
2	114.9	248.5	204.9
3	100.7	263.2	195.5
4	89.5	237.9	166.6
5	90.1	256.2	190.6
6	67.5	202.3	186.3
7	80.3	219.7	156.1
8	74.8	205.0	152.6
9	57.3	169.7	158.4
10	76.3	191.6	142.7
11	71.7	172.7	145.9
12	55.3	149.6	124.1

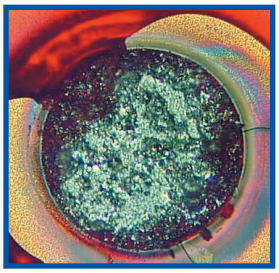

FIGURE 5: Typical cracked surface.

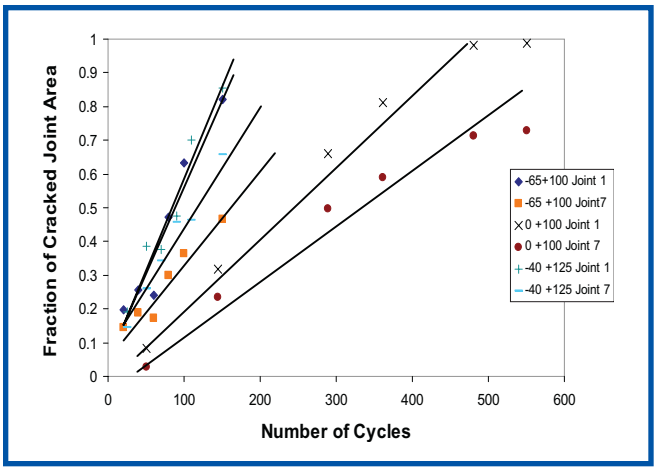

FIGURE 6: Crack growth rate plot.

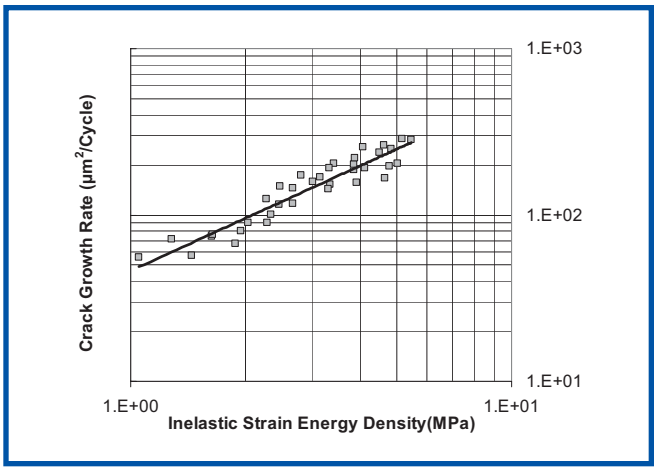

FIGURE 9: Inelastic strain energy density vs. crack growth rate.

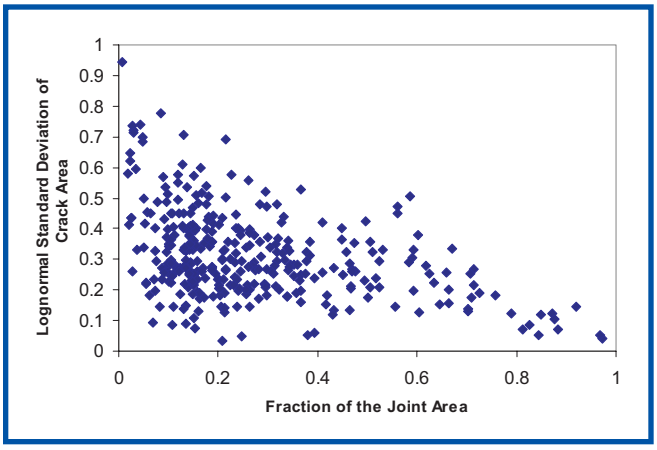

FIGURE 7: Normalized standard deviation in area measurements vs. fraction of fractured area.

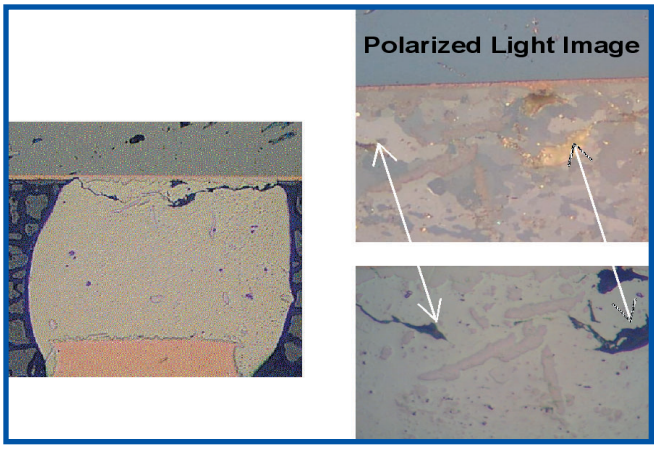

FIGURE 10: Cross-section of a partially failed joint.

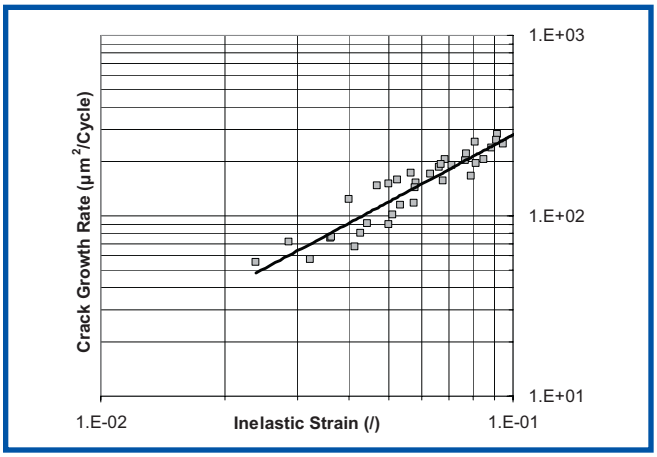

FIGURE 8: Inelastic strain vs. crack growth rate.

Table 3: Fitted Constants for Crack Growth Rate Correlation

Strain (ϵ_{avg})			
Element Thickness (mm)	**Average Element Volume (mm^3)**	**C1(10^{-3} mm^2/ Cycle/(mm/mm)n)**	**n^1**
2.50E-02	4.38E-05	4.3±1.2	1.10
1.25E-02	2.19E-05	4.58± 0.9	1.22
8.33E-03	1.46E-05	4.45± 0.9	1.23
Strain Energy Density (ΔW_{avg})			
Element Thickness	**Average Element Volume**	**C_2(10^{-5} mm^2/ Cycle/MPan)**	**n^2**
2.50E-02	4.38E-05	6.14± 0.48	0.96
1.25E-02	2.19E-05	4.3±0.18	1.05
8.33E-03	1.46E-05	4.06±0.18	1.05

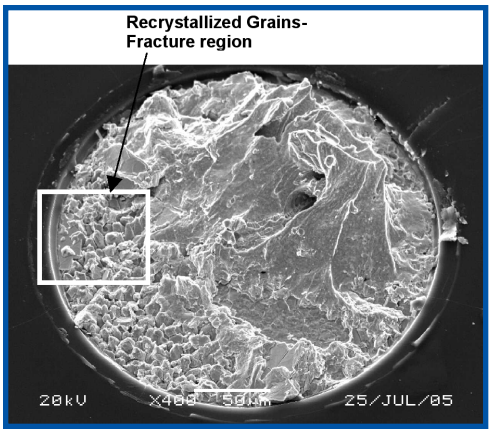

FIGURE 11: SEM analysis of fractured region.

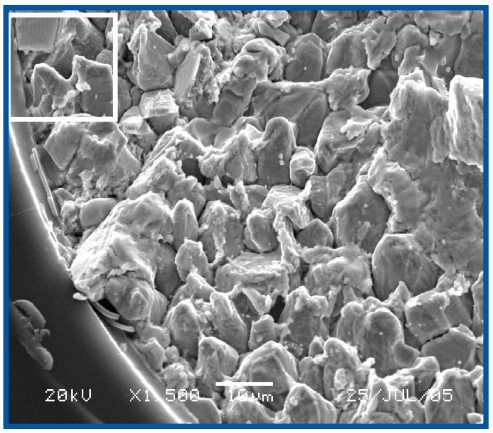

FIGURE 12: SEM analysis of fractured region.

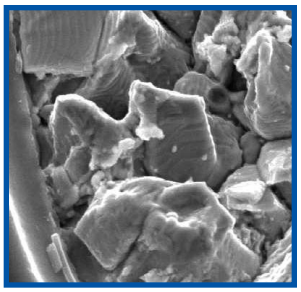

FIGURE 13: SEM analysis of fractured region, showing fracture striations on grains.