Effect of Finite Element Modeling Techniques on Solder Joint Fatigue Life Prediction of Flip-Chip BGA Packages

Xuejun Fan[1], Min Pei[2], and Pardeep K. Bhatti[1]
[1]Intel Corporation, M/S CH5-263, 5000 W Chandler Blvd, Chandler, AZ 85226
[2]Georgia Tech, 801 Ferst Dr. NW, Atlanta, GA 30332-0405

al. [13][14][15] implemented this constitutive model and developed 3-dimensional package level finite element models to perform solder joint creep simulations. This material model can be written as

$$\dot{\varepsilon} = \frac{\dot{\sigma}}{E} + B_1 D \left(\frac{\sigma}{E}\right)^3 + B_2 D \left(\frac{\sigma}{E}\right)^7 \qquad (1)$$

where

$\dot{\varepsilon}$ = Total strain rate (1/sec)

σ = Stress (MPa)

E = Modulus of Elasticity (MPa) = $56000 - 88T$

T = Temperature (K)

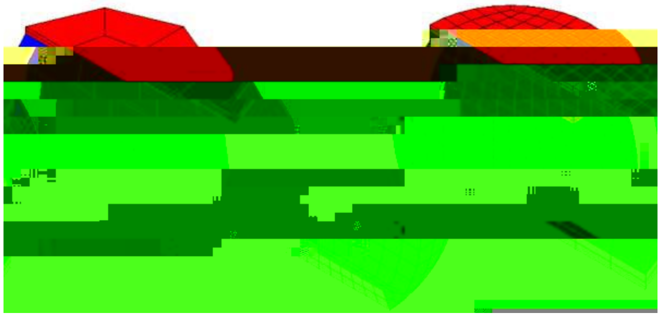
$B_1 = 1.70 \times 10^{12}$ 1/sec

$B_2 = 8.90 \times 10^{24}$ 1/sec

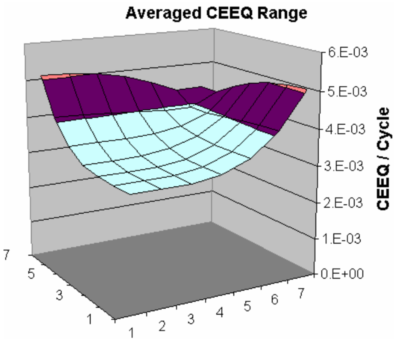
$D = \exp\left(-\frac{5413}{T}\right)$

The second term in the equation (1) accounts for the grain boundary sliding (GBS) creep strain and the third term accounts for the matrix creep (MC) strain.

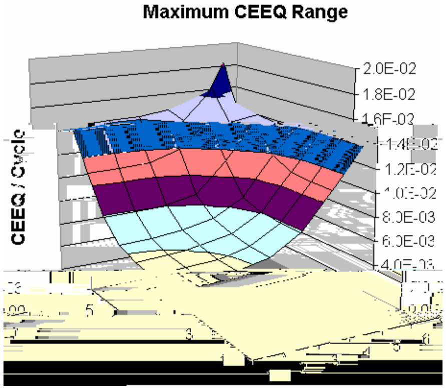
Wiese et al. [11] studied the creep behavior of bulk, PCB sample, and flip chip solder joint samples of Sn/4.0Ag/0.5Cu solder and identified two mechanisms for steady state creep deformation for the bulk and PCB samples. They attributed these to climb controlled (low stress) and combined



model results of a leaded package (e.g. PLCC and QFP) that resulted in less than 5% effect on the creep strain in the critical joint [14]. It is important to note that at the time this



(a) Averaged value

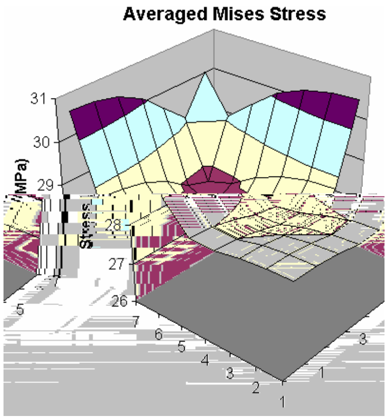


(b) Maximum value

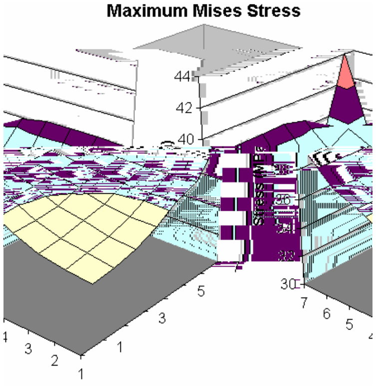
Figure 6: Per-cycle CEEQ distribution over solder balls under the die shadow

From Figure 6(a) the solder joint in the middle of die edge (location 1-7) has the highest per-cycle average CEEQ. All solder joints along the die edge have comparable values within 20% of each other. However, the maximum per-cycle CEEQ, in Figure 6(b), shows the worst-case solder joint at the corner of die shadow (location 7-7), and the second highest value appears one row inside from the die shadow corner (location 6-6). All solder joints along die edge have relatively high strain accumulation.

The averaged and maximum Von Mises stress at the beginning of low-temperature dwell are shown in Figure 7, and show trend similar to CEEQ.



(a) Averaged value



(b) Maximum value

Figure 7: Von Mises stress distribution over solder balls under the die shadow

Following the analysis of Modi et al. [19], the averaged ‘peel’ stress is also plotted in Figure 8. Peel stress is defined as stress in the out-of-plane direction at the solder joint to copper pad interface. It can be seen that the solder joint one row inside from the die shadow corner (location 6-6) has the highest tensile stress. The solder joints under die corner and in the middle of die edge have compressive stress. The averaged hydraulic stress distribution, in Figure 9, shows trend similar to the peel stress.

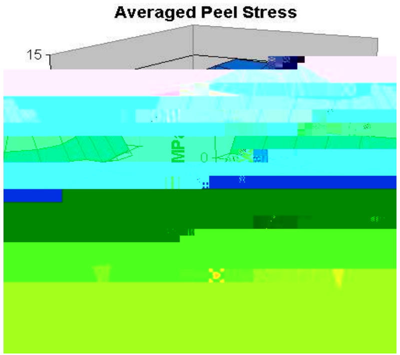


Figure 8: Peel stress distribution over solder balls under the die shadow

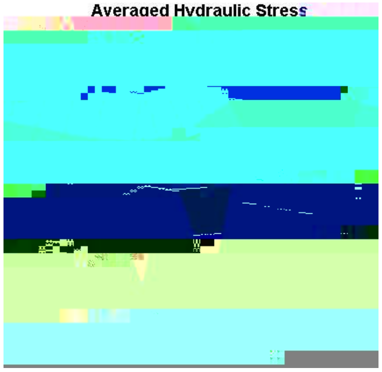
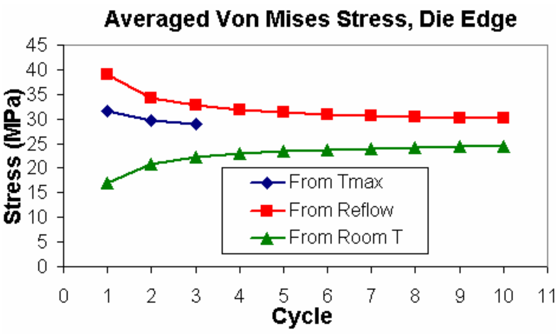
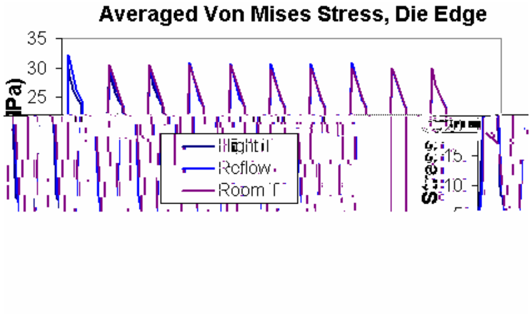


Figure 9: Hydraulic stress distribution over solder balls under the die shadow

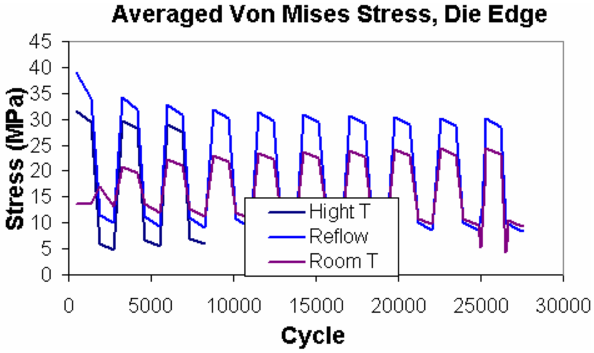
This analysis shows that different parameters give different locations for the worst-case solder joint. Averaged per-cycle creep strain and stre



(b) SnAgCu, peak value



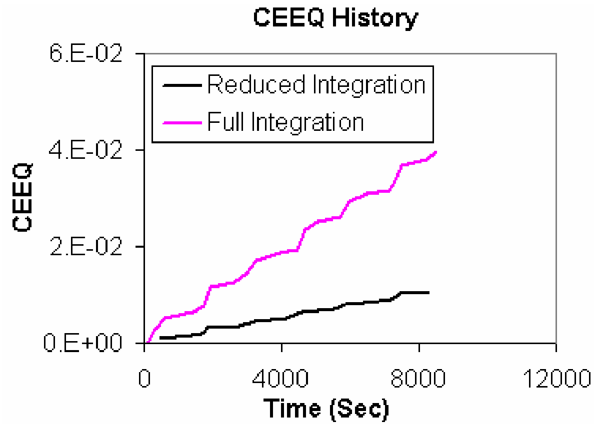
(c) SnPb, history data



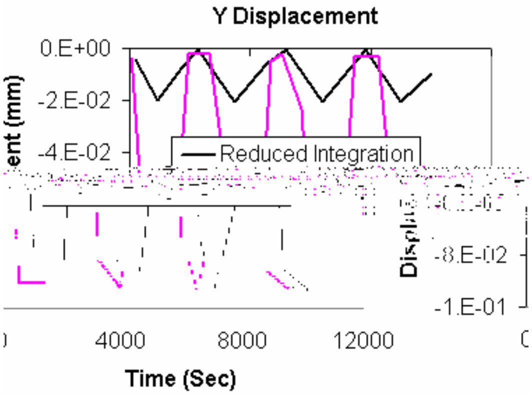
(d) SnAgCu, history data

Figure 11: Averaged Von Mises stress

Figure 12 (a) and (b) show the peel stress distribution for



(a) CEEQ history



(b) Out of plane displacement at solder joint

Figure 13: Comparison of reduced integration and full integration elements

consistent finite element results for the solder joint fatigue in thermal cycling can be achieved when certain guidelines are followed. The following is a summary of our findings and recommendations based on extensive simulation studies:

1. The global/local modeling approach yields satisfactory results if the local model is a cell with one solder ball pitch dimension and no tie constraints are used in the local model other than at the boundaries.
2. Substructure technique can be used without a significant loss of accuracy when most of the structure can be simulated with linear, temperature-independent material properties. However, caution must be used when an assumption of linearization is made.
3. The worst-case solder joint location depends on the selection of the damage metric. It is suggested that the worst-case location be determined by a combination of 'peel' stress and averaged creep strain. A proper damage metric (e.g. averaged accumulated creep strain or strain energy density) at the location of interest can then be used to develop the fatigue life prediction model.
4. Regardless of the initial stress-free temperature, the package always adjusts the stress state to achieve stabilized pattern in temper