Critical Issues in Computational Modeling and Fatigue Life Analysis for PBGA Solder Joints

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Abstract

Fatigue lifetime analysis of solder joints is one of the most critical issues for the development of reliable electronic components. In this study, a nonlinear Finite Element model is used to investigate the effects of variation in material properties, the lifetime analysis index and the temperature profile on the fatigue life of solder joints of a Plastic Ball Grid Array (PBGA) assembly subjected to cyclic thermal loading. The eutectic lead-tin solder is modeled as a visco-plastic material, while the remaining materials are assumed to be elastic. In lifetime analysis, the creep strain range per cycle and the creep strain energy density per cycle evaluated are respectively incorporated into the modified Coffin-Manson equation to estimate the fatigue life of PBGA solder joint under thermal cycling. It is found that the use of these two indices may lead to different conclusions in some situations. A series of parametric studies are also performed by changing the length of dwell time in the temperature profile. The analysis shows a longer dwell time may increase the creep strain range per cycle or creep strain energy density per cycle and result in a reduction of the thermal fatigue life cycles. It is also found that the least cycles to fatigue failure do not correlate to the shortest total lifetime.

Key words:
PBGA, Solder Joint Reliability, Thermal Fatigue, Temperature Profile, and Creep Analysis.

1. Introduction

Recently, the rapid evolving packaging technology has shown that the area array design of Plastic Ball Grid Array (PBGA) package can result in higher board manufacturing yield and better performance, especially for the second-level assembly with an I/O count higher than 208. PBGAs offer significant surface mounting advantages over conventional leaded plastic packages. A primary advantage is that the solder-bumped PBGAs can be attached with extremely low solder joint defect levels. Solder joint assembly defect levels under 20 parts per million solder joints are reported by Motorola, Compaq Computer, and other electronic industries. In contrast, solder defect levels for high pin-count, fine-pitch PQFPs, such as the 208 lead, 0.5-mm PQFP are reported to be 500-2000 parts per million solder joints1.

However, the reliability performance of PBGA solder joints becomes more critical for their short stand-off height caused by the close proximity of the silicon die to the bismaleimide triazine (BT) laminate substrate. The major concern is that the effective coefficient of thermal expansion (CTE) of the PBGA package (die on laminate) is much lower than the rest of the assembly. This fact will result in a relative warpage between the package and the printed circuit board (PCB). Since the PBGA solder joints are the only medium connecting the package and the board, they are designed to withstand thermomechanical mismatch induced warpage in the entire assembly under thermal cycling.

In the literature, there are many efforts deployed to investigate reliability problem of the PBGA solder joint1-5. Due to the difficulty in performing experiments, most of the studies on solder joint reliability are computational modeling. However, it is noted that various studies use different properties to model the Pb37Sn63 solder joint of various packages. In some studied cases, the scattering of a specific material property can even be higher than 50% at a given temperature. This discrepancy can cause many confusions and make the inappropriate reliability study results. Therefore, the first objective of this study is to investigate the effect of variation in material properties on the lifetime of PBGA solder joints.
properties on the fatigue life prediction of solder joints under thermal cycling.

For the thermal fatigue lifetime analysis of PBGA solder joints, the Coffin-Manson equation and its modified versions are one of the most popular approaches. The Coffin-Manson equation in its original form was based on the index of plastic shear strain range. Due to the multi-axial strain state, the shear strain should be modified to be the equivalent inelastic strain range. Recently, the energy method using the index of strain energy has been an alternative as applied for the lifetime analysis of solder joints\textsuperscript{6-8}. The second objective of this study is to evaluate these two indices of the equivalent creep strain range per cycle and the creep strain energy per cycle used in two lifetime analysis methods, respectively.

Although computational modeling is relatively easy to be implemented, the accuracy for life prediction is somewhat questionable. Most of the numerical studies\textsuperscript{1} showed unreasonably large number of life cycles. Therefore, the real fatigue life still needs to be determined by experiments. It is shown that the reliability testing for solder joints under thermal cycling is very time consuming task and can last for several months to complete a new design. If the testing period can be minimized by selecting an optimal temperature profile of thermal cycling, a tremendous amount of time can be saved. A typical temperature profile in general includes three parameters, namely; the temperature range, the ramp time, and the dwell time. The effects of these parameters should be studied prior to the optimal temperature profile determination.

The third objective of this paper is to present a methodology for optimizing the temperature profile of the thermal cycling test for PBGA solder joint reliability. In this study, optimization of dwell time refers to the identification of a temperature profile that leads to the shortest total lifetime. The Finite Element method is employed for this task. Parametric studies will be performed and discussed for identifying the optimal temperature profile.

2. Finite Element Modeling

The package studied in this paper is a 400-ball full grid PBGA with a BT substrate. The solder material is the 63Sn/37Pb eutectic solder. The pitch of 400 PBGA solder balls is 1.27 mm. The package size is 27 mm x 27 mm x 1.25 mm. The silicon die size is 8 mm x 8 mm x 0.38 mm. The BT laminate size is 27 mm x 27 mm x 0.27 mm. The PCB size is 30 mm x 30 mm x 1.52 mm. The thickness of mold compound measured from the BT laminate top is 0.98 mm. These solder joints have a dimension of 0.71 mm in diameter and 0.36 mm in height. The package is assembled on an FR-4 PCB. Solder mask is not considered in the present model. Since the thermal fatigue damage is most critical in the largest planar dimension, only the diagonal cross-section is considered. A schematic diagram of the diagonal cross-section of the package is shown in Figure 1a.

The computational analysis was conducted on a SGI INDIGO 2 workstation with a commercial Finite Element code, ABAQUS\textsuperscript{9}. A preferred maximum time integration step of 10 s was determined for ensuring the solution accuracy. The visco-plastic constitutive equation was implemented into a user-defined subroutine for nonlinear time-dependent deformation analysis. Since all constituents of the assembly have a sizable thickness in the y-direction, the analysis was performed under a plane strain assumption. Due to the symmetry in geometry, only one half of the assembly was modeled. The Finite Element mesh is shown in Figure 1b. The element selected was the 8-node plane strain element. The typical temperature profile is shown in Figure 2. The displacement boundary conditions are: 1) all nodes at the left-hand side of the model are fixed in the x-direction, and 2) the node at the lower bottom of the FR-4 PCB cannot move in the z-direction, as shown in Figure 1b.

Figure 1. (a) Schematic diagram of the diagonal cross-section of a 400-pin PBGA package; (b) The Finite Element mesh and boundary conditions.

The computational analysis for the 63Sn/37Pb solder joint to account for its time and temperature dependence in thermal cycling, while the remaining components are modeled as elastic materials. It is assumed that the total strain rate consists of the elastic, inelastic, and thermal component. The inelastic part is assumed to be dominated by the steady-state creep. The steady-state creep is described by the Norton's power law,
where \( \frac{d\varepsilon_{crp}}{dt} \) is the equivalent creep strain rate; \( \sigma \) is the Mises stress; \( n \) is the stress exponent; \( Q \) is the activation energy; \( k \) is the Boltzmann constant \( (8.63 \times 10^{-5} \text{ eV/K}) \); \( T \) is the absolute temperature, and \( B^* \) is a material constant. It should be noted that, in general, the Norton power law equation is valid only for a range of mild stresses. In the high stress region, other form of constitutive relation should be adopted to account for the mechanical behavior of viscoplastic materials. The material properties of 63Sn/37Pb solder\(^{10,11}\) are given in Table 1. The inelastic part of the constitutive equation can be incorporated into the Finite Element analysis via a user-defined subroutine. In the subsequent stress analysis, the material properties of silicon die, molding compound, BT laminate substrate and PCB\(^{11}\) are listed in Table 2.

Table 1. Material properties of 63Sn/37Pb solder.\(^{10,11}\)

<table>
<thead>
<tr>
<th>E (GPa)</th>
<th>Poisson’s Ratio</th>
<th>CTE(μm/°C)</th>
<th>Q (eV)</th>
<th>( B^* )</th>
<th>( n )</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0.4</td>
<td>21.1</td>
<td>0.49</td>
<td>0.205</td>
<td>5.25</td>
</tr>
</tbody>
</table>

Table 2. Material properties of silicon die, molding compound, BT laminate substrate and PCB.

<table>
<thead>
<tr>
<th>Materials</th>
<th>E (GPa)</th>
<th>Poisson’s Ratio</th>
<th>CTE(μm/°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silicon Die</td>
<td>131</td>
<td>0.3</td>
<td>2.8</td>
</tr>
<tr>
<td>Molding Compound</td>
<td>15</td>
<td>0.25</td>
<td>15</td>
</tr>
<tr>
<td>BT Substrate</td>
<td>26 (x,y), 11 (z)</td>
<td>0.39 (x,y); 0.11 (z)</td>
<td>15 (x,y); 52 (z)</td>
</tr>
<tr>
<td>PCB (FR-4)</td>
<td>22 (x,y), 10 (z)</td>
<td>0.28 (x,y,z); 0.11 (x,z)</td>
<td>18 (x,z); 70 (z)</td>
</tr>
</tbody>
</table>

3. Stress Analysis and Fatigue Life Estimation

Given the formulated model, a cyclic temperature change between \(-10^\circ\text{C}\) and \(90^\circ\text{C}\) with 10 min dwells and 10 min ramps at a frequency of 1.5 cycle per hour (cph) referenced as the base case in Figure 2 was applied for studying the effect of variation in material properties. This temperature profile was also treated as the base case of thermal loading for determining the optimal temperature profile of the thermal cycling test. It was assumed that, at every instant, the temperature distribution of the whole PBGA assembly was uniform.

Figure 3 shows the maximum von Mises stress of each ball along the diagonal direction. It can be seen that the 4th solder ball (#4) from center having the highest values of von Mises stress is underneath the edge of the silicon die. The result of the maximum equivalent creep strain and the creep strain energy density of each ball along the diagonal direction are similar to that of the maximum von Mises stress. This effect can be attributed to the silicon die having a very low CTE (2.8 ppm/°C) and the 4th solder joint has the largest DNP (Distance from the Neutral Point; that is, the center of the package) with respect to the silicon die. Therefore, this solder ball is of the most critical reliability of the PBGA package. Figure 4 gives the contour of the accumulated creep strain energy density of the solder ball #4 at the end of the third cycle. It is found that the largest creep strain energy density occurred at the upper-right corner of the 4th solder ball. The largest equivalent creep strain and von Mises stress also occurred at the same site. The histories of equivalent creep strain and creep strain energy density at this extremely strain location for the base case are presented in Figures 5 and 6, respectively. It is observed that the first cycle behavior of solder joint is very different from the others. This indicates the initial material response of solder joint is not stable. Therefore, quantities from the first cycle will not be included in the subsequent discussion. The stable of creep strain range per cycle, \(\Delta\varepsilon_{crp}^\circ\) and creep strain energy density per cycle, \(\Delta W_{crp}^\circ\), can be estimated in the next several temperature cycles. In FEA, it is recommended to proceed at least three to five cycles for ensuring the occurrence of a stable state.
4. Effects of Variation in Material Properties

It is essential for the computational modeling to have accurate materials properties as input in order to obtain reliable analysis results. However, currently it is still quite difficult to achieve unified materials properties for the PBGA solder joint modeling. This situation may be attributed to the lack of standards for solder material characterization and the difference between bulk and in-situ materials properties. Therefore, a study is needed to estimate the possible error of analysis due to the variation in material properties as shown in the literature2, 4-7, 12, 14-19.

The first objective of this paper aims to perform a sensitivity study on materials properties for the fatigue life prediction of PBGA solder joints under cyclic thermal loading. The materials properties investigated include the Young’s modulus (E), the coefficient of thermal expansion (CTE), and the activation energy of the eutectic 37Pb/63Sn solder alloy. It is noticed that a wide scattering of the aforementioned quantities was reported in literature as given in Table 3.

In this paper, a base case of solder material properties is chosen as given in Table 1. The results of thermal fatigue life estimation, by Finite Element analysis and Equations (2) and (3), with variation in materials properties noted in the literature are presented in Figures 7-9. The normalized lives with respect to that of the base case are shown in Figures 7-9.

Table 3. Material properties (E, CTE, and Activation Energy).

<table>
<thead>
<tr>
<th>E (GPa)</th>
<th>CTE (ppm/°C)</th>
<th>Q (eV)</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>56 (100°C)</td>
<td>-0.088T</td>
<td>6</td>
<td>0.49</td>
</tr>
<tr>
<td>26.5, 12.5, 2.9</td>
<td>-0.3</td>
<td>17</td>
<td>0.519 (or 50 KJ/mol)</td>
</tr>
<tr>
<td>32.4-0.088T</td>
<td>24.7</td>
<td>16</td>
<td>1.137 (or Q/k=13180)</td>
</tr>
<tr>
<td>25 (or 3620 ksi)</td>
<td>0.3</td>
<td>18</td>
<td>0.639 (or 61417 Joule/mole)</td>
</tr>
</tbody>
</table>

In Figure 7, it is found that the increase of the Young’s modulus of the solder material leads to a decrease of the fatigue life of PBGA solder joints for both studied cases. It is also observed that the trend is nonlinear.

The above mentioned $\Delta \varepsilon_{eq}$ and $\Delta W_{cre}$ can be incorporated into the modified Coffin-Manson equation as follows,

$$N_f = \theta_1 (\Delta \varepsilon_{eq})^{\eta_1}$$

$$N_f = \theta_2 (\Delta W_{cre})^{\eta_2}$$

where $N_f$ is the number of cycles to failure, $\Delta \varepsilon_{eq}$ is the equivalent creep strain range per cycle, $\Delta W_{cre}$ is the creep strain energy density per cycle (in psi) and $\theta_1, \theta_2, \eta_1$, and $\eta_2$ are materials constants. The values of $\theta_1 = 0.002277$, $\eta_1 = 2.51$, and $\theta_2 = 7860$, $\eta_2 = 1.0$, were determined for the 63Sn37Pb solder12,13, respectively. It should be noted that, in the original Coffin-Manson equation, the strain range is plastic shear strain range. However, the current PBGA solder joint is considered as elastic-visco-plastic material in this study, the shear plastic strain range in Coffin-Manson equation is replaced by the equivalent creep strain range per cycle ($\Delta \varepsilon_{eq}$) or the creep strain energy density per cycle ($\Delta W_{cre}$) obtained from the Finite Element analysis. In this study, $\Delta \varepsilon_{eq}$ is the averaged equivalent creep strain range of the second and the third cycle as indicated in Figure 5. $\Delta W_{cre}$ is defined as the average creep strain energy density of the second and the third cycle as indicated in Figure 6.
Critical Issues in Computational Modeling and Fatigue Life Analysis for PBGA Solder Joints

The effect of Young's modulus on fatigue life estimation is shown in Figure 7. It is found that the trend of the equivalent creep strain per cycle is the same as that of the creep strain energy density per cycle. Since the range of variation in the literature is not significant, it seems that the influence of Young's modulus on fatigue life prediction is not as strong as that of the CTE. The predicted fatigue life is nearly a linear function of Young's modulus.

The effect of CTE on fatigue life estimation is shown in Figure 8. It is found that the trend of the equivalent creep strain per cycle is the same as that of the creep strain energy density per cycle. Since the range of variation in the literature is not significant, it seems that the influence of CTE on fatigue life prediction is not as strong as that of Young's modulus. The predicted fatigue life is nearly a linear function of CTE.

Figure 7. Effect of variation in Young's modulus on fatigue life estimation.

Figure 8. Effect of variation in coefficient of thermal expansion on fatigue life estimation.

The effect of activation energy on fatigue life estimation is shown in Figure 9. It is shown that the trend of the equivalent creep strain per cycle (Δecp) result is opposite to that of the creep strain energy density per cycle (ΔWcp). When the Δecp is used as the index in Equation (2), it is found that the decrease of the value of the activation energy (Q) may lead to a substantial increase of the equivalent creep strain per cycle. When ΔWcp is used as the index in Equation (3), the result is different from the previous one. It is found that the fatigue life of PBGA solder joints is substantially reduced as the value of the activation energy (Q) increases. The reason is that the creep strain energy density is mainly a function of both creep strain and stress. When the value of Q is smaller, more creep strain is accumulated, but more stress is relaxed as shown in Figure 10. Consequently, less creep strain energy density is accumulated. In these two studied cases, the fatigue life of PBGA solder joints is found to be very sensitive to the value of activation energy. Therefore, it seems that the activation energy of the solder material has the greatest influence on the estimation of thermal fatigue life of PBGA solder joints.

Figure 9. Effect of variation in activation energy on fatigue life estimation.

5. Effects of Temperature Profile

Evaluating the fatigue life of the PBGA solder joints with respect to temperature cycle loads is an important design issue. The goal is set to characterize the fatigue life of PBGA solder joint under accelerated thermal cycling test and that under the field condition. In order to minimize the testing period, an efficient temperature cycle profile is desired. In this section, a series of parametric studies are performed to investigate the effect of temperature range, the length of dwell time and ramp time, and the mean temperature of the thermal cycle. In the first case, both ramp time and dwell time are symmetric to indicate that the ramp up rate is equal to the ramp down rate, the upper dwell time is equal to the lower dwell time (even
dwell time). In the next case, the effect of uneven dwell times on the fatigue life of the PBGA solder joints and total time required to complete the thermal cycling tests was studied. The results of various temperature profiles are summarized in Figures 11-14. Again, the normalized lives with respect to the cycle of the base case temperature profile shown in Figure 2 are presented in Figures 11-14.

The effect of mean temperature on solder fatigue life using $\Delta e_{crp}$ index is shown in Figure 11. Both dwell time and ramp time are equal to 10 minutes. It is found that smaller temperature range leads to smaller amount of creep strain range and a longer solder fatigue life at a given mean temperature. It is also found that the creep strain range is reduced as the mean temperature decreases. In other words, the lower the mean temperature, the longer the solder fatigue life is obtained. The effect of mean temperature on solder fatigue life using the $\Delta W_{crp}$ index is shown in Figure 12. It is found that the results are also insensitive to the change of the mean temperature.

The effect of varying dwell time on solder fatigue life is shown in Figures 13 and 14. These analyses were carried out with the temperature range fixed at 100 °C (-10 °C to 90 °C) and the mean temperature at 40 °C. For $\Delta e_{crp}$ and $\Delta W_{crp}$, the conclusions are the same. It is found that both $\Delta e_{crp}$ and $\Delta W_{crp}$ are reduced as the dwell time decreases for the same ramp time. As a result, the solder fatigue life is a decreasing function of the dwell time.

Figure 11. Influence of mean temperature on fatigue life based on $\Delta e_{crp}$

![Figure 11. Influence of mean temperature on fatigue life based on $\Delta e_{crp}$](image1)

Figure 12. Influence of mean temperature on fatigue life based on $\Delta W_{crp}$

![Figure 12. Influence of mean temperature on fatigue life based on $\Delta W_{crp}$](image2)

Figure 13. Influence of dwell time on fatigue life based on $\Delta e_{crp}$

![Figure 13. Influence of dwell time on fatigue life based on $\Delta e_{crp}$](image3)

Figure 14. Influence of dwell time on fatigue life based on $\Delta W_{crp}$

![Figure 14. Influence of dwell time on fatigue life based on $\Delta W_{crp}$](image4)

Figure 13 also shows the effect of varying ramp time on solder fatigue life based on $\Delta e_{crp}$. It is found that shorter ramp time results in a smaller creep strain range for the same dwell time. Therefore, the shorter the ramp time, the longer the solder fatigue life is for the same temperature range. However, when the $\Delta W_{crp}$ index is used in the modified Coffin-Manson equation, the conclusion (shown in Figure 14) is opposite to that of the $\Delta e_{crp}$. This behavior may be again explained by that the developed stress is an increasing function of activation energy as presented in Figure 10. Although intuitively, longer ramp time leads to more inelastic strain, the internal stresses substantially decrease due to stress relaxation. When the contribution of stress relaxation is larger than the increase in creep strain, the creep strain energy density is actually reduced. Consequently, the longer ramp time may result in longer fatigue life if the lifetime analysis method using the $\Delta W_{crp}$ index is applied.
6. Optimization of Dwell Time

The final objective of this study is to optimize the temperature profile of thermal cycling for the PBGA solder joint reliability so that the reliability test results can be achieved in a shorter test period. In practice, the temperature range and the ramping rate are subjected to the capability of the testing facility. The length of dwell time is the easiest parameter to control in thermal cycling tests. Therefore, the present investigation was focused on the effect of uneven dwell time. In the literature, this methodology was first introduced to simulate PBGA assemblies for a double sided board with the different boundary condition. In the subsequent analysis, all cases have the same temperature range (-10°C~90°C) and the same ramping rate (± 10°C per minute) as the base case (shown in Figure 2). The only parameter to be investigated is the dwell time at the highest temperature (T_u) and at the lowest temperature (T_d).

A series of parametric studies was performed to search for the optimal temperature profile. Nine cases as shown in Table 4 were investigated. Note that all profiles have the same total period per cycle (40 minutes) as the base case. The results of life cycles estimated by Equations (2) and (3), are presented in Table 4. It is found that the case of T_u = 6 minutes and T_d = 14 minutes leads to the least number of life cycles when one adopts the equivalent creep strain per cycle as the index in Equation (2). It is also found that the case of T_u = 3 minutes and T_d = 17 minutes leads to the least number of life cycles when one adopts the creep strain energy density per cycle as the index in Equation (3).

Table 4. Results of life cycles.

<table>
<thead>
<tr>
<th>Case</th>
<th>T_u (min)</th>
<th>T_d (min)</th>
<th>Δε_cr (×10^-3)</th>
<th>Life by Δε_cr (cycles)</th>
<th>ΔW_cr (kPa)</th>
<th>Life by ΔW_cr (cycles)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>20</td>
<td>4.5122</td>
<td>1757</td>
<td>27.6600</td>
<td>1959</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>18</td>
<td>4.8428</td>
<td>1471</td>
<td>28.9020</td>
<td>1875</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>16</td>
<td>4.8428</td>
<td>1471</td>
<td>28.9020</td>
<td>1875</td>
</tr>
<tr>
<td>4</td>
<td>6</td>
<td>14</td>
<td>4.8428</td>
<td>1471</td>
<td>28.9020</td>
<td>1875</td>
</tr>
<tr>
<td>5</td>
<td>8</td>
<td>12</td>
<td>4.8428</td>
<td>1471</td>
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<td>6</td>
<td>10</td>
<td>10</td>
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<td>1875</td>
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<td>4.8428</td>
<td>1471</td>
<td>28.9020</td>
<td>1875</td>
</tr>
</tbody>
</table>

It should be noted that, in practice, the real concern is the total time required to complete the thermal cycling tests, not the total cycles. For the comparison shown in Table 4, since the time period per cycle is a constant, the conclusion on the life cycles applies to the total time to failure as well. However, in order to ensure the identified case 3 and case 6 are also an optimum for the lifetime, further investigations were performed for varying time period per cycle. For the equivalent creep strain per cycle as the index, Figure 15 shows the comparison of lifetime for various cases of T_u while keeping T_d at 3 minutes. Figure 16 also presents a temperature profile with a T_d = 2 minutes may lead to a shortest lifetime of solder joint. It was found that, for the current configuration, the temperature profile for the solder joint with a shortest fatigue life is optimized at T_u = 1 minute and T_d = 2 minutes. The total time period per cycle is 23 minutes. The cycle and the total time to failure are 2,508 cycles, and 40.1 days, respectively.

For the creep strain energy density per cycle as the index, Figure 16 shows the comparison of lifetime for various cases of T_u while keeping T_d at 3 minutes. It was found that, for the current configuration, the temperature profile for the solder joint with a shortest fatigue life is optimized at T_u = 1 minute and T_d = 2 minutes. The total time period per cycle is 23 minutes. The cycle and the total time to failure are 2,508 cycles, and 40.1 days, respectively.
7. Conclusion

In this study, a nonlinear Finite Element model is used to investigate the effects of variation in material properties, the lifetime analysis index and the temperature profile on the fatigue life of solder joints of a Plastic Ball Grid Array (PBGA) assembly subjected to cyclic thermal loading.

1) It is observed that the Young’s modulus of solder in various ranges of value may have a different degree of influence on the life prediction. The effect of CTE seems to be not as significant as the Young’s modulus due to limited range of variation. However, the life cycle is found to be very sensitive to the activation energy of solder.

2) It is found that the lower the mean temperature, the longer the solder fatigue life for the same ramp time. For the ramp time, it is also found that the two response variables, the creep strain range per cycle and the creep strain energy density per cycle, lead to opposite conclusions.

3) It is also observed that the least cycles to failure do not correlate to the total lifetime. A methodology is also presented in this paper to optimize the temperature profile of the thermal cycling test for solder joint reliability. An optimal temperature profile is identified and justified.

References

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