Integrated Flow-Thermomechanical Analysis of Solder Joints Fatigue in a Low Air Flow C4/CBGA Package

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Abstract

This paper presents an integrated flow-thermomechanical analysis of anisothermal fatigue behavior of ceramic ball grid array (CBGA) solder joints in a 32mm C4/CBGA package under a mini power cycled load of one to three watts at a frequency of three cycles per hour. A computational fluid dynamics model was used for conjugate conduction-convection heat transfer analysis to determine the local heat transfer coefficients of package under various low air flow conditions of 0.1 to 0.5 m/s. The determined local heat transfer coefficients were specified as the thermal boundary conditions in a thermomechanical model for transient heat transfer and nonlinear thermal stress analyses to predict the local temperature profiles and associated viscoplastic deformation of CBGA solder joints. Using a deformation base lifetime analysis method, the predicted mean fatigue life of the power cycled solder joints are compared to that of the temperature cycled solder joints under a 0/100°C load. Predictions of temperature cycled solder mean life show good agreements with experimental data. Analysis shows that the leading edge and trailing edge CBGA solder joints in the package have different fatigue behavior. This air flow induced orientation effect grows significantly as the air flow velocity increases. Both temperature cycled and power cycled solder fatigue results were used to estimate the equivalent solder fatigue lives of the C4/CBGA packages with application to the laptop and desktop computer systems at an average on-off temperature rise $\Delta T$ of 20°C and 30°C.

Key words: Solder Joints, Reliability, Viscoplasticity, Local Heat Transfer Coefficient, Ceramic Ball Grid Array (CBGA), and Finite Element Analysis.

1. Introduction

The Ceramic Ball Grid Array (CBGA) structure is an extension of IBM C4 (controlled collapse chip connection or called Solder Bump Flip Chip (SBFC)) technology to provide a highly reliable solder array interconnection for surface mounting ceramic modules to standard epoxy glass Printed Circuit Boards (PCB) and cards. Trends towards the cost-performance requirement of computers, telecommunications, and consumer electronic systems have created a growing need for the use of a high I/O density C4/CBGA package. The common feature of these systems is that the available design space for the thermal management is very limited and is expected to be functional in a low air flow environment due to system miniaturization. As in many electronic systems, thermal fatigue of the CBGA solder joint plays a limiting role in the reliability of low air flow C4/CBGA package. Design for such special application requires a thorough understanding of the fundamental problems compounded by thermal management and mechanical reliability of the package. Appropriate modeling methods and analysis tools for an integrated flow-thermomechanical and reliability analysis are recommended in the concurrent design process.
In the integrated flow-thermomechanical analysis, the determination of the interrelated quantities of temperature, stress, and deformation in and around an electronic package in a convective environment presents a complex problem. From a strict viewpoint of the coupling thermal boundary effects of the solid and the fluid, the entire problem must be considered as a unit, and these interrelated quantities have to be solved simultaneously. However, for most practical packaging engineering problems, the effect of stresses and deformations upon the temperature distributions (such as material internal friction) is quite small and can be neglected. This assumption allows the determination of temperature response in the heat transfer analysis to be decoupled from the stress and the deformation analysis of an electronic package. Thus, the heat transfer problem of the package can be formulated with the convection boundary conditions imposed over the package surfaces that include the convection effect of local heat transfer coefficients in the low air flow environment. In literature, the Flat Plate Correlation (FPC) method has been widely used to calculate the convective heat transfer of electronic packages where a constant value of heat transfer coefficient can be directly obtained by an empirical expression. Moffat and Ortega, however, revealed a concern that the direct use of the FPC method without a dynamic similarity justification may lead to an inaccurate prediction problem mainly caused by neglecting the effects of flow blockage and the many length scales. To release this concern, a more accurate treatment of the determination of local heat transfer coefficient is necessary.

Yuan used a Computational Fluid Dynamics (CFD) model to study the conjugate conduction-convection heat transfer problem of various convected flip chip and wirebond CBGA packages. It was found that the flow-thermal boundary depends strongly on the fluid flow conditions which could not be empirically represented by the FPC method. The accurate use of a CFD model cannot only ensure the reliable determination of the local heat transfer coefficient, but also significantly affect the thermal management solution for the problems of interest. For the integrated thermomechanical analysis of electronic packages, Wilson and Nakayama suggested the use of local heat transfer coefficients on the package surfaces in the Finite Element analysis to sequentially calculate the local temperature and thermal stress distributions. Recently, Hong and Yuan presented an integrated flow-thermomechanical analysis for a wirebond CBGA package under various convective air flow conditions. Thermal boundary conditions, including the local and the constant heat transfer coefficients, and their effects on steady state temperature profiles and thermally induced stresses of package components were compared to that of a simple isothermal case with a constant temperature profile. Hong et al. further extended this approach to study the transient heat transfer induced anisothermal fatigue behavior of solder joints of a convective wirebond CBGA package under power cycling. Similar approach was applied to study the solder joints fatigue of a low air flow, flip chip Plastic Ball Grid Array (PBGA) package. It was concluded that the approaching air flow could introduce the significant orientation effect on the local temperature and the thermal fatigue behavior of Ball Grid Array (BGA) solder joints. The predicted power-cycled solder fatigue life was significantly different from that of the temperature cycling.

The goal of this paper is to present the use of an integrated flow-thermomechanical analysis method in predicting the histories of the local temperatures, and their effects on the induced viscoplastic deformation and fatigue life of the CBGA solder joints in a C4/CBGA package under various low air flow conditions.

2. Problem Formulation and Analysis

The package in this study, as shown in Figure 1, was a 625-ball C4/CBGA single chip module (SCM) assembly. A 13mm x 13mm x 0.75mm chip is bonded to the top surface of a 32mm x 32mm x 2mm ceramic substrate by the C4 solder bumps with an encapsulant-underfill. At the back surface of this package, a fully populated 25 x 25 array of CBGA solder joints are bonded onto the molybdenum pads of the ceramic substrate in a 1.27mm I/O pitch. This C4/CBGA package was finally attached to the copper pads of a 156mm x 107mm x 1.57mm FR-4 card in a high temperature reflow process with a temperature of 210 to 215°C peak (above the melting point, 183°C, of eutectic Pb37-Sn63 solder) in approximately 60 seconds. In the CBGA solder joint, a Pb90-Sn10 ball of 0.762mm in diameter is embraced by the eutectic Pb37-Sn63 solder fillets at both ends. A design of large pad and small solder-volume CBGA solder joint was assumed. The FR-4 card used in this study was assumed to contain the metal layers and has a thermal conductivity of 13 W/m-K. Detailed configuration and material properties of the package are listed in Table 1.

Table 1. Material properties of C4/CBGA package.

<table>
<thead>
<tr>
<th>Material</th>
<th>Dimension (mm)</th>
<th>Temp. (K)</th>
<th>Elasto. Modulus (MPa)</th>
<th>Poisson Ratio</th>
<th>Yield Strength (MPa)</th>
<th>CTE (ppm/K)</th>
<th>Thermal Conductivity (W/mK)</th>
<th>Specific Heat (J/kgK)</th>
<th>Density (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>0.76 thick</td>
<td>298</td>
<td>83.3</td>
<td>0.28</td>
<td>102</td>
<td>6.7</td>
<td>4.1</td>
<td>136</td>
<td>2.8</td>
</tr>
<tr>
<td>Si Substrate</td>
<td>0.76 thick</td>
<td>156</td>
<td>1000</td>
<td>0.28</td>
<td>80</td>
<td>3.7</td>
<td>1.0</td>
<td>86</td>
<td>3.3</td>
</tr>
<tr>
<td>Silica Glass</td>
<td>0.76 thick</td>
<td>373</td>
<td>1000</td>
<td>0.28</td>
<td>80</td>
<td>3.7</td>
<td>1.0</td>
<td>86</td>
<td>3.3</td>
</tr>
<tr>
<td>Moly</td>
<td>0.76 thick</td>
<td>298</td>
<td>300000</td>
<td>0.28</td>
<td>80</td>
<td>3.7</td>
<td>1.0</td>
<td>86</td>
<td>3.3</td>
</tr>
<tr>
<td>Pb50Sn50</td>
<td>0.76 Dia</td>
<td>273</td>
<td>252</td>
<td>0.40</td>
<td>14.1</td>
<td>37.9</td>
<td>38</td>
<td>190</td>
<td>6.5</td>
</tr>
<tr>
<td>Pb60Sn40</td>
<td>0.76 Dia</td>
<td>273</td>
<td>252</td>
<td>0.40</td>
<td>14.1</td>
<td>37.9</td>
<td>38</td>
<td>190</td>
<td>6.5</td>
</tr>
<tr>
<td>Cu Pad</td>
<td>0.025 thick</td>
<td>298</td>
<td>22.0</td>
<td>0.378</td>
<td>59.0</td>
<td>16.7</td>
<td>0.39</td>
<td>182</td>
<td>8.8</td>
</tr>
<tr>
<td>FR-4 Card</td>
<td>1.57 thick</td>
<td>298</td>
<td>472000</td>
<td>0.28</td>
<td>80</td>
<td>3.7</td>
<td>1.0</td>
<td>86</td>
<td>3.3</td>
</tr>
</tbody>
</table>

Figure 1. The schematic of C4/CBGA (Ceramic Ball Grid Array) package.
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For computational efficiency, only a single array of CBGA solder joints and hybrids in the central, longitudinal direction of the package was modeled. A two dimensional Finite Element model, as shown in Figure 2, was created using the I-DEAS® design and simulation program. The 8-node plane element was selected to model the complicated geometry of solder joint for reducing the number of elements with acceptable solution accuracy. The model has a total of 1,296 elements and 4,799 nodes. The modeled package was power cycled under various convective cooling conditions with air flow velocity of 0.1 m/s, 0.2 m/s and 0.5 m/s, respectively. A cyclic power load of 1 to 3 watts with 100 s ramps and 800 s dwells was assumed in the modeled package. For comparison, a constant temperature cycling condition was simulated that a 0-100°C with 5 min ramps and 5 min dwells. Both power and temperature cycling conditions had a frequency of 3 cycles per hour (cph). The detailed procedures for integrated flow-thermomechanical and reliability analysis of this C4/CBGA package are described as follows, section 2.1.

2.1. Flow-Thermal Analysis

The main objective of flow-thermal analysis was to determine the local heat transfer coefficients being used as the thermal boundary conditions in predicting the temperature profile for thermal fatigue life analysis of the CBGA solder joints. In this study, the researchers considered this C4/CBGA assembly was inside a computer cabinet. The computational domain in Cartesian coordinate system is shown in Figure 1. A CFD model was created to have a domain size of 156 mm in length (x-direction), 107 mm in width (z-direction) and 36 mm in height (y direction). The lower and the upper channel height is 10 mm and 24mm, respectively. The conjugate thermal boundary is handled by applying the harmonic mean average of the thermal diffusivities between the fluid and the solid interfacial control volumes. This practice assures the heat flux across the control volume at the interface be satisfied as depicted in Patankar. A typical grid independent solution requires the grid size of 40 x 30 x 25 in this CFD model.

The air flow is assumed to flow over the packages on both sides of the card. The inlet conditions are set with uniform inlet velocity and temperature distributions. Outlet boundary conditions assume the velocity and temperature gradients to be zero. No slip conditions are specified at all wall boundaries. At the side and top wall surfaces, adiabatic thermal conditions are assumed. This study focuses on the forced convection heat transfer as the gravity effect is estimated to be very small. Assuming incompressible laminar and steady flow, a set of governing conservation equations with appropriate boundary conditions must be solved by an appropriate numerical solution scheme. In this study, a Finite Difference control volume method in a CFD program Fluent was used.

The CFD analysis results were used to calculate the local heat transfer coefficients along the package surface. Figure 3 provides the local heat transfer coefficient distributions at both the top and the bottom surfaces of the C4/CBGA package. It can be seen that the heat transfer coefficients predicted are not constant and are present in a nonuniform distribution along the package surfaces due to the flow blockage and length effects. The trend shows that the local heat transfer coefficient is an increasing function of the air flow velocity. These local heat transfer coefficients would be prescribed as the thermal boundary conditions in a Finite Element model, as shown in Figure 2, for the thermomechanical analysis.

2.2. Thermomechanical Analysis

In this section, a sequential transient heat transfer and nonlinear stress analysis using a nonlinear Finite Element program ABAQUS® was implemented for studying the thermomechanical problem of the C4/CBGA package. In the sequence of analysis, the pre-determined thermal boundary condition of local heat transfer coefficients (Figure 3), and a cyclic power load of 1/3W, 3cph were applied to a transient heat transfer model for calculating the local temperature profile of the modeled package. The obtained temperature profile was stored as an input file and treated as the cyclic temperature loads in a subsequent thermal stress model to calculate the power cycling induced viscoplastic strain response of interest. Due to the different characteristics, two different types of ABAQUS® plane elements, DC2D8 and CPS8, were used for transient heat transfer and thermal stress model, respectively.
In this work, nonmetallic materials are assumed to be linear elastic, and metallic and alloy materials are elastic-plastic and viscoplastic, respectively. A constitutive theory based on the classical creep and plasticity concept was used in modeling temperature dependent viscoplastic deformation behavior of the Pb-Sn solders as developed by Hong and Burrell. In this theory, the total strain is assumed to be the sum of the elastic, the plastic, the creep, and the thermal strain. The Garofalo hyperbolic sine law was applied to model the creep behavior with the advantage of covering the low and high stress regimes as follows,

$$\varepsilon^c = A\left[\sinh(B\sigma)\right]^n \exp\left(-\frac{Q}{RT}\right)$$  \hspace{1cm} (1)

where $\varepsilon^c$ is the uniaxial tensile creep strain, $\sigma$ is the applied uniaxial tensile stress in MPa, $A$ and $B$ are material constants, $n$ is the stress exponent, $Q$ is the apparent activation energy in J/mole, $R$ is the gas constant (8.314 J/mole-°K), and $T$ is the absolute temperature in °K, respectively. The Prandtl-Reuss equation was used for representing the time-independent plastic deformation. Figures 4 and 5 provide the temperature dependent stress-strain data of Pb90-Sn10, and Pb37-Sn63 solder alloy, respectively. Relevant material properties and constants of the package components are listed in Table 1.

For the case of temperature-cycled condition (0/100°C, 3 cph), a uniform constant temperature distribution was prescribed across the whole package. Due to the symmetry, only one half of the cross section of the package was modeled. It is noted that the room temperature of $T = 27°C$ (300°K) is treated as the initial power and stress free temperature, for transient heat transfer and thermal stress model, respectively.
3.2. Local Temperature Responses

Figure 6 gives the peak local temperature histories of the package components subjected to an air flow of \( U = 0.2 \) m/s. The temperature of 300°K is defined as the ambient temperature. It is seen that the temperature fluctuates in a wave shape, and tends to reach a saturated state after three power cycles. The peak temperature occurs when the chip power reaches three watts in each cycle. As expected, the chip is the heat source and has the highest peak temperature response in the package. A temperature excursion with range of 342 to 374°K is found in chip after three power cycles. The approaching air flow also results in nonuniform temperature distributions in the solder joints and card. In the saturated state, the Trailing Edge (TE) solder joint has a peak temperature of 370°K that is approximately 5°K higher than the Leading Edge (LE). A similar but more significant gradient in peak temperature response can be seen between the leading edge (\( T = 313°K \)) and the trailing edge (\( T = 342°K \)) of the card. The maximum temperature gradient in card is about as 29°K at \( U = 0.2 \) m/s. The other two convective conditions result in a maximum card temperature gradient of 32°K for the \( U = 0.1 \) m/s, and 23°K for the \( U = 0.5 \) m/s, respectively.

Figure 7 shows the effect of air flow velocity on chip temperatures. An increase of air flow velocity does help reduce the chip temperature. Figure 8 gives the temperature histories of the CBGA solder joints at the two extreme locations (LE and TE) with respect to the air flow direction. The extreme temperatures (\( T_{\text{max}} \) and \( T_{\text{min}} \)) and the temperature rise from the ambient (\( \Delta T_{\text{max}} = T_{\text{max}} - T_{\text{amb}} \)) of the power cycled CBGA solder joints are listed in Table 3. The maximum temperature occurs when \( P_{\text{chip}} = 3 \) W, and the minimum temperature when \( P_{\text{chip}} = 1 \) W, respectively. The temperature gradients between the leading edge and the trailing edge solder joint are not sensitive to the air flow velocity. These gradients are about 5°K for
3.3. Fatigue Life Prediction

Based on the above calculated temperature profiles, the thermally induced deformations and stresses of the package components were determined in the power-cycled CBGA package. The analysis shows that the CBGA solder joint has a maximum inelastic deformation that is highly concentrated in and around its eutectic Pb37-Sn63 solder fillet-shoulder (card or substrate attachment) area with structural singularity. It was compared to know that the substrate side solder fillet attachment has a deformation that is higher than the card side. Figure 9 presents the histories of the equivalent inelastic strains $\varepsilon_{eq}^{in}$ (or IEEQ) for the eutectic Pb37-Sn63 solder fillets in the CBGA solder joints. Comparisons are made between the power-cycled and the temperature-cycled CBGA packages. The $\varepsilon_{eq}^{in}$ is defined as the sum of the equivalent creep strain $\varepsilon_{eq}^{cr}$ (or CEEQ) and the equivalent plastic strain $\varepsilon_{eq}^{pl}$ (or PEEQ). The accumulation rate of inelastic strain grows in the first two cycles and gradually decreases to reach a saturated state after the third cycle. It should be noted that the time-independent plastic strain only developed in the temperature cycled (0/100°C, 3cph) CBGA solder joint but not in that of the power-cycled (1/3W, 3cph) cases. This is mainly due to the thermal stress rise is not high enough to initiate the plastic deformation in solder joints under the small temperature excursions caused by power cycles, See Figures 6 through 8. On the other hand, the accumulated creep strains were found to predominate in the total inelastic strain of the CBGA solder joints in both power and temperature cycled conditions. The researchers therefore treated the creep strain response as a major fatigue damage index of the CBGA solder joint to be used in lifetime analysis in this study.

It is also observed that the trailing edge CBGA solder joint of the power cycled package has a maximum creep strain that is higher than that of the leading edge. This suggests that the most severe fatigue damage will occur in the trailing edge CBGA solder joint at various air flow conditions. In the temperature cycled case, the CBGA solder joints have creep strain response that are symmetric with respect to the package center. The substrate edge CBGA solder joint has the highest creep strain than any other solder joints.

In this study, the saturated range of equivalent creep strain $\Delta \varepsilon_{eq}^{cr}$ was used as a measure to interpret the accumulated thermal fatigue damage. The characteristics of the saturated creep strain range $\Delta \varepsilon_{eq}^{cr}$ of the CBGA solder joint, as observed above, makes possible the use of a deformation base lifetime prediction method\(^{16}\) to calculate the solder joint mean fatigue life as follows,

$$N_{50} = B_1 (\Delta \varepsilon_{eq}^{cr})^c$$  \hspace{1cm} (3)

where material constants used are $B_1 = 0.146$ and $c = -1.94$ for the eutectic Pb37-Sn63 solder joint with a fatigue damage mechanism predominated by creep deformation\(^{17}\). The predicted $\Delta \varepsilon_{eq}^{cr}$ of both power cycled and temperature cycled CBGA solder joints are listed in Table 3. The maximum value of $\Delta \varepsilon_{eq}^{cr}$ at the integration point of Finite Element in each extreme edge solder joint was recorded. To validate the use of this set of material constants in model prediction, the temperature cycled CBGA model was modified to simulate a condition of 0/100°C with two other frequencies of 1.33 cph and 2 cph, respectively. In the case for the frequency of 1.33 cph, the model predicted $N_{50}$ is 467 cycles that has a good agreement with the $N_{50} = 446$ cycles in the experiment\(^{18}\). Similarly, good correlation results were found for the frequency of 2 cph that the predicted $N_{50}$ is 539 cycles versus the experimental $N_{50}$ of 479 cycles\(^{19}\). However, it should be noted that the material constants for $B_1$ and $c$ are very selective to the package type (PBGA versus CBGA), the solder pad size and the solder volume, and the dominated viscoplastic deformation mode (creep versus plasticity). Therefore, the correlation and prediction must be undertaken with care.

![](image-url)
solder joint $N_{01}$ were made between the power cycled and temperature cycled condition as shown in Table 3. The power-cycled solder joint life for the $U = 0.1$ m/s is $3.4x$ that of temperature cycling. When the air flow velocity increases, this factor is increased to be $6.37x$ for the $U = 0.2$ m/s, and $16.4x$ for the $U = 0.5$ m/s, respectively. It is clear that the increase of air flow velocity does enhance the fatigue life of the CBGA solder joints. One can also see that the leading and the trailing edge CBGA solder joints have different mean fatigue lives and the difference is growing as the air flow velocity increases. This may indicate a fact that different factors of design for packaging reliability should be included to justify the use of Accelerating Thermal Cycling (ATC) test data for product qualification and application.

Given the calculated $N_{01}$ as listed in Table 3, the CBGA solder joint fatigue life at a failure rate of $x\%$ can be estimated using a two-parameter (2P) Weibull statistical distribution model,

$$N_f (x\%) = N_f (50\%) \left[ \frac{\ln (1 - 0.001x)}{\ln (0.5)} \right]^{1/\beta}$$  \hspace{1cm} (4)

where $\beta$ is the Weibull shape parameter or slope of the Weibull probability plot. The value of $\beta$ varies and depends on the type of solder joints. It was reported that typically $\beta = 3$ for general material fatigue tests. In the low acceleration package fatigue test, $\beta = 4$ for the stiff leadless solder joint, and $\beta = 2$ for compliant leaded attachments. Higher $\beta$ values were used to correlate with the thermal fatigue data, for example, $\beta = 12.3$ for the CBGA and the Ceramic Column Grid Array (CCGA) solder joints, and 9.92 $\leq \beta \leq 47.9$ for PBGA solder joints, respectively.

In this study, the Weibull slope $\beta = 12.3$ was used to estimate the $N_{01}$ (0.01% or 100 ppm) and $N_f$ (0.1% or 1000 ppm) of Weibull population to fail of the CBGA solder joint as listed in Table 3. $N_{01}$ is often used as a measure of how each distribution extrapolates to a very small failure rate for large sample size that would be expected in the field. An example is given in this case to illustrate the use of predicted results, as listed in Table 3, for a practical reliability design analysis with application to the laptop and desktop computer systems.

### 3.4. Example

In consideration of the system level thermal and reliability design option with the $\Delta T$, the typical and upper temperature bounds that may be expected during product usage are 25-45°C ($\Delta T = 20^\circ C$) and 25-55°C ($\Delta T = 30^\circ C$), respectively. Given the field assumptions that on the average, the system would be turned on and off one time a day for 365 days each year, and the system would be cycled over the full thermal excursions, by applying the frequency-modified Coffin-Manson law,

$$N_{field} = N_{lab} \left( \frac{T_{field}^{max} - T_{lab}^{max}}{T_{field}^{max}} \right) \frac{T_{field}^{max}}{T_{lab}^{max}} \exp \left[ \frac{1}{14.14} \frac{1}{365} \frac{1}{1.414} \right]$$  \hspace{1cm} (5)

One can estimate the equivalent solder joint fatigue life $N_{01}$ for the field applications. The symbol $N$ denotes the number of on-off cycles, $f$ is the frequency, $T_{field}$ the highest on-temperature, $\Delta T$ is the range of cyclic temperature, the value of 1.414 in $^\circ K$ is an empirical activation temperature for the eutectic Pb37-Sn63 solder, and the subscripts of field and lab represent the field and laboratory conditions, respectively. When the temperature cycled CBGA $N_{01}$ data, as shown in Table 3, was used as the laboratory condition, the field equivalent $N_{01}$ would be approximately 2,347 cycles (or 6.5 years in life) for $\Delta T$ of 30°C, and 5,870 cycles (or 16 years) for $\Delta T$ of 20°C, respectively. On the other hand, if the power cycled CBGA data for 0.1 m/s $< U < 0.5$ m/s were used as the laboratory conditions, the equivalent field fatigue life would be 3,246 cycles (or 8.89 years) $< N_{01} < 4,577$ cycles (or 12.5 years) for the $\Delta T$ of 30°C, and 7,013 cycles (or 19.2 years) $< N_{01} < 9,887$ cycles (or 27 years) for the $\Delta T$ of 20°C, respectively. The temperature cycled data give predictions that are more conservative than the use of the power cycled data in product reliability qualification. A power cycled prediction, however, would lead to a better estimate for the solder field life of a real electronic package in use.

### 4. Conclusions

In this study, the authors can summarize several important aspects based on the integration of flow, thermal, thermomechanical and reliability analyses and results for a low air flow C4/CBGA package under power cycling as follows. 1) The use of CFD solutions can assure the accurate prediction of local heat transfer coefficients of the package. The use of local heat transfer coefficients in Finite Element model for transient heat transfer and viscoplastic deformation analysis allows to bridge the temperature gradient history to the thermal fatigue response of the CBGA solder joints. 2) At various low air flow conditions of $U = 0.1$ to 0.5 m/s, the mini power cycling life of the first-failed CBGA solder joint was predicted to be 3.4x to 16.4x that of the 0/100°C temperature cycling. This indicates that the power cycled C4/CBGA package has a CBGA solder joint fatigue behavior that is significantly different from that of temperature cycling. The effect of air flow upon the viscoplastic deformation and the thermal fatigue behavior of the power cycled CBGA solder joints is significant. The leading and the trailing edge CBGA solder joints have different fatigue response which can be clearly qualified and quantified. It is recommended that appropriate design factors should be considered to justify the use of the reliability test results for product applications. 3) With application of an average on-off $\Delta T$ of 30°C or 20°C to the laptop and desktop computer systems, the use of temperature cycled results gives an estimated filed fatigue life of C4/CBGA package that is more conservative than that of the power cycled predictions.
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References


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