Fatigue Life Evaluation of Lead-free Solder under Thermal and Mechanical Loads

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Abstract
In this study, two types of fatigue tests were conducted. First, cyclic bending tests were performed using the micro-bending tester. A four-point bending test method was adopted, because it induces uniform stress fields within a loading span. Second, thermal fatigue tests were conducted using a pseudo power cycling machine which was newly developed for a realistic testing condition. The pseudo-power cycling method makes up for the weak points in a power cycling and a chamber cycling method. Two compositions of solder are tested in all test condition, one is lead-free solder (95.5Sn4.0Ag0.5Cu) and the other is eutectic lead-contained solder (63Sn37Pb).

In the cyclic bending test, the solder that exhibits a good reliability can be reversed depending on the load conditions. The lead-contained solders have a longer fatigue life in the region where the applied load is high. On the contrary, the lead-free solder sustained more cyclic loads in the small load region. A similar trend was detected at the thermal cycling test. Furthermore, to certify the crack behavior, the failed specimen was sectioned. In thermal cycling case, crack initiated inner solder joints. But outmost solder failed first in the cyclic bending test.

A three-dimensional finite element analysis model was constructed. A finite element analysis using ABAQUS was performed to extract the applied stress and strain in the solder joints. A constitutive model which includes both creep and plasticity was employed. Thermal fatigue was occurred due to the creep. And plastic deformation is main damage for bending failure. From the inelastic energy dissipation per cycle versus fatigue life curve, it can be found that the bending fatigue life is longer than the thermal fatigue life.

Introduction
Recently, the use of mobile devices has increased: cellular phones, personal data assistants (PDA), MP3 players, DVD players, portable multimedia players (PMP), and so on. In these mobile devices, the packages were exposed to the thermal and bending loads. The thermal loads were caused due to the thermal coefficient mismatch between different materials. Handing, key pressing and dropping induced bending loads on the solder joints. And, sometimes, mechanical and thermal load are combined together. These loads make the failure of solder joints. So the reliability tests need to be performed not only under thermal fatigue loading but also under mechanical fatigue loading.

Many researchers performed thermal cycling test for various type of package using thermal chamber. And the cyclic bending test also was started, because the use of mobile device has been increased. As a result of previous study, thermal cycling behavior of solder joints was revealed brightly [1-4] and bending fatigue behavior has been uncovered [5-7]. But the relationship between thermal and bending fatigue behavior was not discovered yet. In this study, main object is to increase the understanding of the relationship between thermal and bending fatigue behavior.

Pseudo-Power Cycling Machine
Thermal fatigue tests were conducted with a pseudo-power cycling machine, which gives more realistic testing condition and higher efficiency of thermal fatigue test. Generally the power-cycling tests are required power (heating) chip and a precise control technique [8-9]. It is exhausting work, so almost researchers do the chamber-cycling test. But the chamber-cycling test has many shortages. In the chamber, the package and PCB suffer same temperature change. This isothermal condition makes over- and under-estimation according to the difference of thermal expansion and the applied temperature range. And the chamber-cycling test required long testing time, because heat is transferred by convection. To overcome the power- and chamber-cycling test, the pseudo-power cycling test method was proposed [10]. The pseudo-power cycling method ensures similar temperature gradient at the solder ball joints with the power-cycling testing case, [11] During the pseudo-power cycling, heat is transferred by conduction and that could reduce the temperature rising and cooling times, which decrease the overall thermal cycling time.

A schematic view and a real photograph of the pseudo-power cycling machine are presented at Fig. 1 and 2. In order to achieve a uniform temperature distribution on the contact surface with the package, a shape of ‘Test Base’ and cooling channel’s size, position and interval were designed through the finite element analysis. The heating block could generate maximum 4kW of heat. There are 12 cooling channels, where the coolant flow directions are opposite to next one. The temperatures of package and PCB, daisy chain’s resistance were measured in real-time using the Keithley 2700 DMM with 7700 modules. The measured data was recorded on the PC. Moreover the PC makes the heater and coolant control signals automatically.

```
Solder Ball Joint
Package

Test Base

Heater

Cooling Channel

PCB

Fig. 1. Schematic view of pseudo-power cycling machine.
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1-4244-0985-3/07/$25.00 ©2007 IEEE 95 2007 Electronic Components and Technology Conference
In the pseudo-power cycling test, the heat transfer from the heater to package, so the package temperature goes up first and then the PCB temperature follow that. As a result, there exists a temperature gradient between the package and PCB like the power-cycling case. And the coolant takes heat out of the chip. If the coolant exist in the cooling channel during heating period, temperature of ‘Test Base’ dose not go up, so at the end of cooling period the coolant was blown out. Detail descriptions on the pseudo-power cycling test method are listed elsewhere [11].

Specimen and Testing Condition for Thermal Cycling Test

For thermal cycling test, two types of specimen were used, one (type #1) was designed specially for fast testing, and the other (type #2) is a conventional PBGA package. Type #1 specimen was shown as Fig. 3. For the type #1 specimen, two identical FR-4 PCBs of 2.0mm thickness were bonded by 36 solder joints, where 9 solder joints were laid on each corner. A lower PCB (white gray part at the Fig.3) which is used alike package is 40mm by 39mm and a upper PCB (dark gray part in the Fig.3) is 38mm by 34mm. The diameter of solder joints is 760µm and the pitch of solder joints is 1.27mm. For failure detection, daisy-chain is constituted.

Type #1 has large size and small number of solder ball joints, it make the package weaker than conventional package. Because the large size induce large thermal expansion mismatch between upper and lower PCB and small number of solder joints means that each solder joints endure more stress even if the same CTE mismatch was happened. As a result, an acceleration test is possible using the type #1 specimen.

Fig. 4 presents the type #2 specimen, which is composed of 256 PBGA (plastic ball grid array, white gray part) package made by Top Line Co. and PCB (dark gray part). This type #2 specimen was tested to verify that the test results of type #1 could be applied to real package and to make the correlation with bending test results, where 256PBGA at the type #2 specimen is identical with package used in the bending test mentioned below. The 256PBGA package has 27×27×0.36 mm substrate with a 10×10×0.3 mm silicon die and 1.17 mm-thick over-mold. There are 256 solder balls with a diameter of 760 µm where the ball pitch was 1.27 mm and the solder balls are arranged with 4 peripheral rows. PCB size is 40×40×2 mm and PCB is composed of FR4. For failure detection, daisy-chain is also constituted. Type #2 takes very long time to complete the thermal cycling test, because it is a good designed package. Two types specimen have same solder ball size (760µm), ball pitch, solder compositions and PCB finish (Ni/AuSpecimens were flowed in N₂ atmosphere through the reflow machine which ensured same temperature profiles according to the solder composition.

The specimens are just placed on the top of the ‘Test Base’. Thermal grease was applied to the contact surface of ‘Test Base’ to increase the conductivity between the ‘Test Base’ and package. It has enough viscosity to maintain the contact between package and the top surface of ‘Test Base’. The testing conditions for type #1 specimen are listed on the Table 1 and 2. The thermal test for type #2 specimens was conducted only one test condition (30~150ºC), because it takes a very long time.
Table 1. Testing conditions of thermal cycling test for type #1.

<table>
<thead>
<tr>
<th>Material</th>
<th>Temperature Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>63Sn37Pb</td>
<td>30–150 °C</td>
</tr>
<tr>
<td>63Sn37Pb</td>
<td>30–125 °C</td>
</tr>
<tr>
<td>63Sn37Pb</td>
<td>30–110 °C</td>
</tr>
<tr>
<td>63Sn37Pb</td>
<td>30–100 °C</td>
</tr>
<tr>
<td>63Sn37Pb</td>
<td>30–75 °C</td>
</tr>
<tr>
<td>95.5Sn4.0Ag0.5Cu</td>
<td>30–150 °C</td>
</tr>
<tr>
<td>95.5Sn4.0Ag0.5Cu</td>
<td>30–130 °C</td>
</tr>
<tr>
<td>95.5Sn4.0Ag0.5Cu</td>
<td>30–110 °C</td>
</tr>
<tr>
<td>95.5Sn4.0Ag0.5Cu</td>
<td>30–100 °C</td>
</tr>
<tr>
<td>95.5Sn4.0Ag0.5Cu</td>
<td>30–90 °C</td>
</tr>
<tr>
<td></td>
<td>30–70 °C</td>
</tr>
</tbody>
</table>

Table 2. Time period of thermal cycling test

<table>
<thead>
<tr>
<th>Period</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total cycle time</td>
<td>7.5 min</td>
</tr>
<tr>
<td>Heating time</td>
<td>3 min</td>
</tr>
<tr>
<td>Holding time</td>
<td>3 min</td>
</tr>
<tr>
<td>Cooling time</td>
<td>1.5 min</td>
</tr>
<tr>
<td>Cycles per day</td>
<td>196 cycles</td>
</tr>
</tbody>
</table>

Experimental Results of Thermal Cycling Test

Fig. 5 describes the temperature on the upper and lower PCB in type #1 specimen. The temperature profile is similar with the power cycling test. In this study, the holding time is very short for fast testing, so the upper PCB’s temperature did not saturated. If holding time is increased, the lower PCB’s temperature saturated as lower temperature in comparison with lower PCB’s temperature. The temperature difference ($\Delta T$) according to the time is depicted in Fig. 6. $\Delta T$ is calculated by Eq. 1. As shown in Fig. 6, the shape of $\Delta T$ has similar trend on the various conditions and the amplitude is changed according the testing condition. The minus $\Delta T$ was happen during the cooling period, because the lower PCB, which play a package role, is cooled first.

\[
\Delta T = T_{upper PCB} - T_{lower PCB}
\]  

(1)

Failure is defined when the resistance of the daisy chain exceeds 0.6\,\Omega. Initial resistance of the daisy chain was 0.35\,\Omega of room temperature, and 0.48\,\Omega at high temperature region (150°C). Higher temperature causes the thermal expansion on copper traces, so their length became longer and their area is reduced, which leads to increase the resistance of daisy chain. Fig. 7 presents the changing trend of a daisy chain resistance. At early stage without any failures, the resistance profile followed the temperature profile of specimen as mentioned above. As the crack initiates and propagates, the resistance is increased and become unstable. When the crack is propagated thoroughly, the daisy chain is broken and the resistance goes to infinite. The resistance behavior showed irreversible process: once an unstable phenomenon started, it never become stable again. Hence, this failure criterion is thought to be reasonable.

Pseudo-power cycling test results are arranged and summarized using Weibull distribution (detail data are shown in [11-12]). For type #1 specimen, the relationship between thermal fatigue life and $\Delta T$ is described in the Fig. 8. There existed cross points between the lead-contained solder and the lead-free solders. In large $\Delta T$ regions lead-contained solder (63Sn37Pb) had a good fatigue resistance, but in small $\Delta T$ regions lead-free solder (95.5Sn4.0Ag0.5Cu) had a longer fatigue life. According to the result in Fig. 8, the solder which exhibit a good reliability could be reversed defending on the testing conditions. For type #2 specimen, characteristic life of lead-free solder and lead-contained solder is 4770 and 2616 cycles, respectively. The Weibull plot of type #2 is revealed as Fig. 9.
Bending Test – Tester, Specimens, Condition and Results

In this study, 4-point bending test was conducted using micro-bending tester, which is developed for electronic package test. The 256PBGA package were used in thermal cycling test (as type #2 specimen’s package) is adopted for the bending test. Fig.10 shows the bending specimen. In the bending test, increased load could accelerate the test even if 256PBGA was used, because mechanical load could increase easily in comparison with thermal load.

Detail specifications of the bending tester and the specimen will be published other paper [13]. And that paper gives a full explanation of the test results. In this paper, it is summarized. Bending test results are described in the Fig.11. At each level, tests were repeated more than five times and the representative values were selected as the average. That result is similar to the thermal cycling test. Under high load conditions, lead-contained solders have longer fatigue life. On the contrary, lead-free solder sustain more cyclic loads under small load conditions. According to Figures 8 and 11, it can conclude that lead-free solder has good fatigue resistance in small load and lead-contained solder could sustain large loads.

Failure Site Inspection

To identify the cracking behavior in the solder joints, the failed specimen was inspected. To obtain clearer crack path, the loading was continued after daisy-chain was broken. If fatigue test was stopped at the failure detecting moment, the crack propagated through just one solder joint and initiation site on that solder joint could not distinguished from the sectioning.

Failure specimens were mounted using epoxy and proper mold. And then it sectioned diagonally. The sectioned surface is polished with sandpaper (#600, #1000, #1500 and #2000) and diamond compound (1µm). Fig.12 and Fig.13 show the diagonally sectioning views of type #2 of thermal cycling and bending specimen, respectively. At the sectioned surface, there are 8 solder joints (each 4 solder joints near the edge, named as #1 to #8). The crack was marked with red bar, where some interfaces between the solder and pad seem likely crack but it just scratch. The hardness difference between two materials happens to dig out at the interface, so it looks like a crack. It is validated by higher zoom lens.

Fig.12 presents the crack position and length of lead-contained solder at thermal cycling case of 30~150ºC. The upside of solder is PBGA package and downside is PCB in the picture. The crack initiated several points successively. Crack length maximizes at the inner solder joints (#4, #5), and is getting to decrease as go outside. Main crack happen at PBGA and solder interface but some cracks also observed at interface between PCB and solder. When the thermal loads were applied, the PCB bended as like an umbrella. It induces rotation of solder joints, so pulling force applied at right-up edge and left-down edge (see #3 and #4 solder joints). But opposite side solder joints (#5 and #6) get the pulling force at symmetry position, such as left-up and right-down edge. This result agrees well with the finite element analysis results, described in the following section.
Fig. 13 shows the fatigue cracks after the cyclic bending test for lead-free solder joints. The fatigue crack length is increased as the distance from the center is increased. The crack propagated through the entire solder joints at the outermost (#1 and #8). The solder #7 has also a penetration crack, but that was caused by void. The solder #2 has half crack, and inner solders do not have any crack. Form that, it can say that the crack is initiated at the outermost solder joints and is propagated to the inner. The cracks were observed only at the interface between the solder and PCB. In this study, uniform stress was applied near package to in-plane direction on the PCB. The PCB pulls the solder joints toward outside of the package. Therefore outmost solder joints, especially at the interface between PCB and the solder, undergo higher stress than inner one. It also was agreed with finite element analysis.

**Finite Element Models**

In the experiment, exact stress and strain could not measure directly, because the shape of solder joint is complex and applied stress tensor is complicated. Therefore, finite element analysis using ABAQUS was performed to extract the applied stress and strain at the solder joints. For precision drawing and good quality mesh, a three-dimensional finite element model was constructed from the modeling software Partran. Due to the symmetry, only one-eighth of the package was modeled for type #1 and #2 thermal cycling specimen and quarter was modeled for cyclic bending specimen. For the calculation efficiency, important solders were meshed finely, and the others were meshed coarsely. At all of the model, the solder joint shape is identical and the material properties are also same, as the real solder’s shapes and properties are same in the experiment.

The FE model of type #1 and #2 for thermal cycling test were consisted with 20,962 elements (25,110 nodes) and
31,945 elements (39,091 nodes), respectively. Fig.14 and Fig.15 shows FE model of type #1 and #2, respectively. In those pictures, the solder joints, PCB and mold are represented as light blue, green and black color, respectively.

![Fig.14. FE model for type #1 of thermal cycling test](image1)

![Fig.15. FE model for type #2 of thermal cycling test](image2)

Table 3. Material properties for finite element analysis

<table>
<thead>
<tr>
<th>Temperature (K)</th>
<th>Temperature Density (kg/m³)</th>
<th>Specific Heat (W/mK)</th>
<th>CTE (ppm/K)</th>
<th>Elastic Modulus (MPa)</th>
<th>Poisson Ratio</th>
<th>Yield Strength (MPa)</th>
<th>Strain (0/0.01/0.1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FR-4</td>
<td>1938</td>
<td>879</td>
<td>listed below</td>
<td>22000 (X,Y)</td>
<td>0.11 (X,Y)</td>
<td>117000</td>
<td>0.34</td>
</tr>
<tr>
<td>Copper</td>
<td>8942</td>
<td>385</td>
<td>389</td>
<td>16.7</td>
<td>0.34</td>
<td>69.0</td>
<td>elastic</td>
</tr>
<tr>
<td>Epoxy</td>
<td>228</td>
<td>383</td>
<td>0.2</td>
<td>6.68</td>
<td>0.35</td>
<td>23000</td>
<td>elastic</td>
</tr>
<tr>
<td>Silicon</td>
<td>273</td>
<td>323</td>
<td>2330</td>
<td>2.8729</td>
<td>0.2783</td>
<td>130194</td>
<td>elastic</td>
</tr>
</tbody>
</table>
The FE model for bending test has 60,656 elements and 75,343 nodes (Fig. 16). In Fig.16, the numbers indicate the viewing directions and corresponding side views. And red, yellow, light blue, dark blue and green represent PCB, solder joint, mold, substrate and loading rod, respectively. Loading rod is modeled as analytical rigid body whose shape calculated from mathematical equation. The length of loading rod seems short, but during the calculation it functions as infinite.

All of these FE models were made to have same mesh size and shape, because generally the FE analysis results depend on the mesh size and shape. The material properties of the models come from website and Park, Hong and Lau’s works [14-16] where creep properties of 95.5Sn3.9Ag0.6Cu is selected for 95.5Sn4.0Ag0.5Cu solder due to the lack of available material data. A constitutive model that includes both creep and plasticity was employed. And some properties whose temperature dependency is critical were described to reflect that effect. Adopted material models are listed in Table.3.

<table>
<thead>
<tr>
<th>Material</th>
<th>A (1/s)</th>
<th>B (1/MPa)</th>
<th>n</th>
<th>Q (J/mole)</th>
</tr>
</thead>
<tbody>
<tr>
<td>63Sn37Pb</td>
<td>12423</td>
<td>0.126</td>
<td>1.89</td>
<td>61417</td>
</tr>
<tr>
<td>95.5Sn4.0Ag0.5Cu</td>
<td>44100</td>
<td>0.005</td>
<td>4.2</td>
<td>44995</td>
</tr>
</tbody>
</table>

Fig. 16. FE model for cyclic bending test

Fig. 17. Out-of-plan deformation of PCB under package.

Fig. 18. Von-Mises stress distribution
Finite Element Analysis Results

There is a large difference between the deformation shape of bending and thermal cycling specimen. Fig.17(a) and (b) show the out-of-plane deformation of PCB under the PBGA package. The circle marks indicate the position of solder joints. In the bending test, the PCB is twisted as shown in Fig.17(a). Along to bending load direction, deformation of PCB is increased. However the deformation is decreased along to the transverse direction and magnitude of that is one-third compared with loading direction. In the 4-point bending test, force stretched the PCB to the loading direction, then PCB shrinkage was occurred to the transverse direction due to the Poisson’s ratio. In contrast with bending specimen, the deformed shape is symmetrically radial in thermal cycling specimen (Fig.17(b)). Because it cased by CTE mismatch between PCB and package.

The applied stress distribution on the solder balls are shown in Fig.18. In the bending cycling test, high stresses are loaded at the outmost corner solder balls but in the thermal cycling test, maximum stress occurs at inner solder balls. Moreover in bending cycling test, maximum stress occurs at the interface between the solder and PCB, but in thermal cycling test, maximum occurs at the interface between the solder and package. These results are in good agreement with the physical inspection of the failed specimen. Bending load is extrinsic force, so the load translates outer solder to inner one. Therefore, outer solder joints endure almost loads, so the load transferred to inner solder joint is little. But thermal load is intrinsic force. The inner solder endure loads which are occurred by PCB expansion due to CTE mismatch, especially the expansion of center area where there are no solder joints.

Fig.19 and Fig. 20 shows the energy dissipation during cycling tests. The energy dissipation was calculated from

\[ E = \sum_{i=1}^{n} W V_i \]  

where energy E, energy density W and volume V is in J, J/m³, m³, respectively. And n is number of interest elements. For the convenience, dissipation energy and dissipated energy density per cycle are designated as E and \( \Delta W \), respectively. And the subscript cr, pl in and represent the creep, plastic and inelastic (total) energy, respectively. \( \Delta W \) means that the volume averaged increase of E during one cycle on the stable cycles. \( \Delta W \) was calculated from

\[ \Delta W = \frac{\sum_{i=1}^{n} dE_i}{\sum_{i=1}^{n} V_i} \]  

where dE is increase of E during a cycle at stable stage.

For the exact analysis, \( E_{cr} \) and \( E_{pl} \) are distinguished from \( E_{in} \). FE analysis was conducted until 30 cycles for bending and type#1 specimen. Because the enough time is need to stabilize \( \Delta W \). For type #2, FE analysis was performed 10 cycles. FE analysis is required much time and computing power, our resource is not enough, so until now just 10 cycles analysis was done.

In the thermal cycling tests, \( E_{cr} \) is larger than \( E_{pl} \), all of the case as shown in Fig.19. As thermal load is increased, the \( E_{cr} \) and \( E_{pl} \) increased, especially \( E_{cr} \) is prominent. The \( E_{pl} \) is saturated after 10~20 cycles, however, \( E_{cr} \) is almost linear from the initial cycles. The \( \Delta W_{cr} \) is about 40 to 90 times larger than \( \Delta W_{pl} \) for type #1 specimen and is 7 times larger for type #2. These facts mean that plastic deformation, which occurred in early stage, was disappeared on stable stage.

On the contrary, \( \Delta W_{pl} \) is about 2 to 7 times larger than \( \Delta W_{cr} \) in cyclic bending tests (see Fig.20). Except the 1~26 N loading case, \( \Delta W_{cr} \) is about 2 times larger, even if \( E_{pl} \) is larger than \( E_{cr} \) as shown in the Fig.20. On the 1~26N case, large plastic deformation is occurred in early stage, and then an increase rate of plastic deformation is suddenly decreased. Therefore, \( \Delta W_{cr} \) is larger at the cyclic stable stage. The ratio of \( \Delta W_{pl} \) to \( \Delta W_{cr} \) is increased as the applied load is increased. On high load test condition (over 30N), \( E_{pl} \) is not saturated and is accumulated as damage. From Fig. 19 and Fig. 20, there is the distinction between the major energy dissipation mechanisms on thermal and bending test, and it could be found that creep is principal damage in thermal cycling test and plasticity is essential damage in cyclic bending test.

There are many types of fatigue life prediction models. Typically, strain- and energy- damage based models is used for solder. If strain-based life prediction model was applied for bar type specimen, it is suitable. However, strain distribution of solder joint is very complex. In order words, each place on the solder joint has different strain. It is very difficult to decide where the representative position is. Therefore energy based model is adopted for damage parameter. For the universal use, volume normalized value \( \Delta W \) is substituted for \( \Delta E \).

The correlation between \( \Delta W_{in} \) and the fatigue life for lead-free solder is depicted in Fig 21. \( \Delta W_{in} \) is averaged value of whole solder joint. Some data are taken from Park experiments [15]. Park performed the mechanical tension-compression fatigue test with the exactly same solder and PCB with this study. The mechanical test, which is tension-compression test or bending test, could be described as linear relationship in log-log scale. But thermal cycling test results deviate from the mechanical one. There are many possible causes which could induce this phenomenon. But it is not clear in this study.
Fig. 19. Energy dissipation at the lead-free solder joint during the thermal cycling test

Fig. 20. Energy dissipation at the lead-free solder joint during the cyclic bending test

Fig. 21. $\Delta W_{in}$ vs. fatigue life curve for lead-free solder.

Fig. 22. $\Delta W_{in}$ at the interface vs. fatigue life curve for lead-contained and lead-free solder joints

The Morrow’s energy based life prediction model is described as

$$N_f^m \Delta W_{in} = C$$  \hspace{1cm} (4)

where $m$ and $C$ is fatigue exponent and material ductility coefficient, respectively. This model applied to the mechanical test results, then below equation could be obtained roughly.

$$N_f^{0.87892} \Delta W_{in} = 110.655$$  \hspace{1cm} (5)

Fig.22 shows the relationship between $\Delta W_{in}$ and fatigue life for lead-contained and lead-free solder joints. In Fig.22, $\Delta W_{in}$ is averaged with critical interface elements, not entire solder ball elements. The results seem to imply that the lead-contained solders have higher fatigue resistances than the lead-free solders, in some sense. However, it should be noted that a direct comparison would not provide any meaningful insight. Above all, these two solders have different material ductility coefficient and fatigue exponent in the Morrow energy model. And, despite an identical applied load, the stress and strain induced on the lead-free solder joint are different from those of the lead-contained one. In other words, $\Delta W_{in}$ for lead-contained solder has larger value than lead-free solder at the same loading condition. This is due to the different material constant, such as elastic modulus, yield stress, and tangent modulus. At the same load condition, $\Delta W_{in}$ for lead-contained solder is larger than lead-free one, because it has lower yield stress.

Conclusions

In this paper, the mechanical cyclic bending test and thermal cycling test were performed. And the pseudo power cycling method, developed to better simulate the real operating condition, was introduced. From experimental result, it was found that the lead-free solder ($95.5Sn4.0Ag0.5Cu$) has a stronger fatigue resistance than the lead-contained solder ($63Sn37Pb$) under low loading levels in both thermal and bending tests. But, when the applied load
increased, the lead-contained solder has a longer fatigue life. In the thermal cycling test, crack start at the inner solder joints and propagated to the outer one. On the contrary, crack initiated at the outermost solder at corner in the cyclic bending test.

Non-linear finite element model which includes the creep and plastic constitutive equations was constructed and analyzed. The PCB was twist during bending test due to the Possion’s ratio and was bended radial symmetry for thermal cycling test. The mechanical test results could not be applied directly to thermal test. The failure mechanism is different between two types of load, creep is principal damage in thermal cycling test and the plasticity is prominent factor in cyclic bending test. From experiment and FE analysis, the understanding of difference between the thermal and bending cycling tests was increased.

Acknowledgments
This research was supported by Ministry of Science and Technology in Korea through “Development of Reliability Design Technique and Life Prediction Model for Electronic Components”.

References