Reliability Analysis of LCCC Leaded Solder Joints Under Thermal Cyclic Loading Conditions

Zhang Yukun, Zhang Chun and Xu Weiling
Beijing Institute of Space Mechanics&Electricity, Beijing, China

Keywords: LCCC Package, Finite Element, Thermal Fatigue Life.

Abstract: In this paper, a finite element analysis model of the stress-strain of the solder joints of LCCC package devices is established to analyze the stress-strain of the solder joints of LCCC devices under temperature cyclic loading, and the effect of the substrate material on the thermal fatigue life of the solder joints is analyzed. The results show that the use of Al_2O_3, the same material as the LCCC package, as the substrate can effectively improve the thermal fatigue life of the solder joints under thermal cyclic loading conditions. In practical applications, the Al_2O_3 material transfer method can be used to improve the thermal fatigue life of LCCC package devices.

1 INTRODUCTION

LCCC (Leadless Ceramic Chip Carrier) devices are widely used in electronic products in various industries due to their small size, high pin density, high speed and high frequency. However, due to the large difference in thermal expansion coefficients between the packaging material and the FR4-based PCB, the cyclic stress and strain on the solder joints between the components and the PCB will be caused under the action of high and low temperature cycles, and when the thermal cyclic stress reaches a certain number of times, it will cause the solder joints to crack, which are used for mechanical support and electrical connection in the electronic packaging structure, and the cracked solder joints will eventually lead to component failure. Therefore, it is important to study the stress-strain law of LCCC package solder joints under thermal cyclic loading. This research has been carried out by scholars. The stress-strain distribution of plastic ball grid array (PBGA) devices under thermal cyclic loading conditions has been investigated, and laminated solder joints have been used to improve the thermal fatigue life of solder joints under thermal cyclic loading conditions(Wei et al., 2013). Some scholars have analyzed the variation of thermal fatigue life with solder joint materials by applying thermal cyclic loads to solder joints of different materials by experimental methods(Gao et al., 2018; Gao et al., 2018),. Some scholars have studied the thermal fatigue life of LCCC package devices under -30℃ ~50℃ temperature cycling conditions based on finite element simulation and engineering algorithm respectively(Hou et al., 2014). The influence of filler adhesive parameters on the reliability of lead-free solder joints based on the Anand intrinsic model was investigated(Zhang et al., 2000). The results showed that the elastic modulus of the filler adhesive has no significant effect on the thermal fatigue life of the solder joints, while the coefficient of linear expansion of the material has a significant effect on the thermal fatigue life of the solder joints.

The above literature does not discuss the influence of solder joint height and substrate material on the reliability of LCCC packages under temperature cyclic loading conditions. In this paper, the stress-strain analysis of LCCC devices based on ANSYS finite element analysis software is used to study the effect of change in solder joint height and substrate material on the thermal fatigue life of LCCC devices to further improve the reliability of the solder joints of LCCC devices.

Yukun, Z., Chun, Z. and Weiling, X.
Reliability Analysis of LCCC Leaded Solder Joints Under Thermal Cyclic Loading Conditions.
DOI: 10.5220/0011933300003612
In *Proceedings of the 3rd International Symposium on Automation, Information and Computing (ISAIC 2022)*, pages 372-376
ISBN: 978-989-758-622-4; ISSN: 2975-9463

2 LCCC PACKAGE THERMAL CYCLING STRESS-STRAIN FINITE ELEMENT ANALYSIS

2.1 Finite Element Model of LCCC Package Solder Joints

The object of analysis in this paper is the LCCC (leadless Ceramic Chip Carrier) package, the model entity is derived from the CMOS image sensor produced by BAE, the device body size is 40mm × 50mm × 4.5mm, a total of 194 pads, pad center spacing of 0.8mm, the bottom pad size is 1.4 mm × 0.38mm. To reduce the impact of PCB edge stress strain on the solder joint, the PCB size is taken to be two times the size of the device package, the PCB size is 80mm × 100mm × 2mm. The selected solder joint material is Sn63Pb37 solder paste.

Considering the actual situation of the printed circuit board on the copper wire filling glue and other materials to establish a finite element model is very difficult, in order to improve the efficiency of the analysis, shorten the analysis time, the model will do some simplification process. In this paper, the LCCC geometric model design assumptions: 1) ignore the printed board manufacturing process used in the filling glue and other materials and the influence of metal compounds between the solder joints; 2) all parts of the model are ideally connected, ignoring defects such as voids in the solder joints; 3) when the ambient temperature changes, the overall temperature of the package are equal, there is no temperature gradient; 4) the initial temperature of 25 ℃, the initial stress inside the package is 0.

2.2 Material Ontology Equations and Parameters

Due to the more obvious inelastic stress-strain characteristics of lead-tin materials, in the finite element analysis of the solder joints using Anand viscoplastic instantonal equation to describe its mechanical behaviour. Sn63Pb37 solder paste material performance parameters are shown in Table 1. The parameters of the Anand model for Sn63Pb37 solder paste are shown in Table 2.

Table 1: Material properties of Sn63Pb37 solder paste.

Temp.(℃)	Elastic modulu(GPa)	Poisson
-55	47.97	0.352
-35	46.89	0.354
-15	45.79	0.357
5	44.38	0.360
20	43.25	0.363
50	41.33	0.365
75	39.45	0.37
100	36.85	0.77

Table 2: Anand model material parameters for Sn63Pb37 solder paste.

S_0(MPa)	Q/R(K^{-1})	A(sec^{-1})	ξ	m	h_0(MPa)	$\hat{s}$(MPa)	n	a
12.41	9400	4.0e6	1.5	0.303	1378.95	13.79	0.07	1.3

The PCB board for each anisotropic linear elastic material, ceramic package, copper solder tray and the rest of the parts are each homogeneous linear elastic material. Material parameters are shown in Table 3.

Table 3: The remaining material properties.

Materials	Elastic modulu (GPa)	Poisson ratio	CTE (10^{-6}1/K)
Al_2O_3	310	0.22	7
FR-4PCB(x,y)	35	0.12	20.6
FR-4PCB(z)	14	0.12	68.3
Solder pads	110	0.34	17

2.3 Modeling and Boundary Conditions

The model is simplified to a quarter structure considering symmetry, Visco107 viscoplastic solid cells are used for the weld joint cell type, and Solid45 solid cells are used for all other structures. Establish the finite element analysis model and mesh division as shown in Fig. 1 and Fig. 2. Symmetry constraints are applied to the x-z and y-z symmetry planes of the model, and full constraints are applied to the symmetry center nodes on the bottom surface of the PCB.

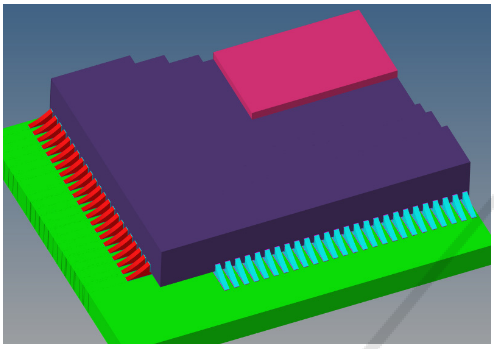

Figure 1: LCCC finite element analysis model.

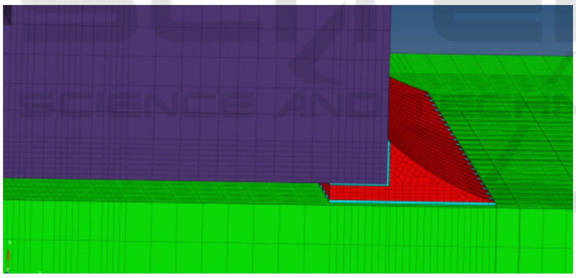

Figure 2: Model mesh division.

2.4 Thermal Cycle Loading Condition

The thermal cycling load is applied with reference to a standard, the initial temperature is set at room temperature 25°C, the upper temperature 100°C, the lower temperature -55°C, the high and low temperature limits are insulated for 900s, the temperature change rate does not exceed 0.17°C/s, each cycle 3600s. The loading curve is shown in Figure 3. The finite element analysis was calculated using 4 temperature cycle cycles.

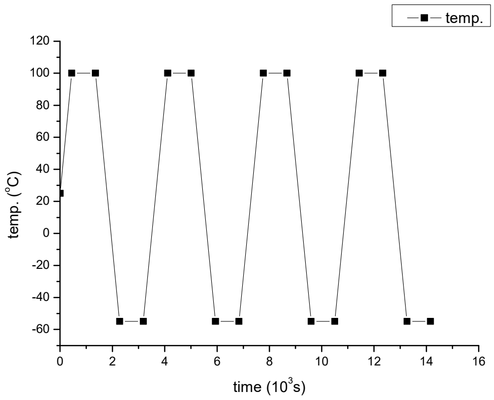

Figure 3: Temperature cycling condition.

2.5 Stress-Strain Finite Element Analysis Results

After four thermal cycles, the equivalent plastic strain distribution in the interior of the solder joint at the end of the fourth week of holding for Sn63Pb37 solder joints is shown in Figure 4.

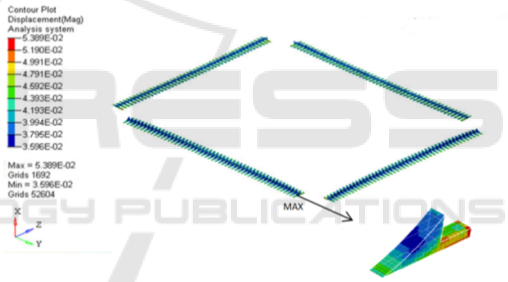

Figure 4: Equivalent plastic strain distribution

The figure shows that the maximum equivalent force and strain of the device are located at the sharp corners. Under thermal cycling loading conditions, the solder joints at the sharp corners of the device are critical solder joints. The critical solder joint reaches the maximum equivalent plastic strain at the end of the high temperature holding period of 0.05389. The maximum strain inside a single solder joint is located at the intersection of the bottom and side pads of the device.

The stress-strain results of the critical weld joint were extracted and the stress-strain hysteresis curve was plotted as shown in Figure 5. It can be seen that the curve is gradually converging to the hysteresis loop shape, and the fourth cycle hysteresis loop is selected to obtain the plastic strain range of the critical weld joint within one temperature cycle is $\Delta\varepsilon = 0.0216$.

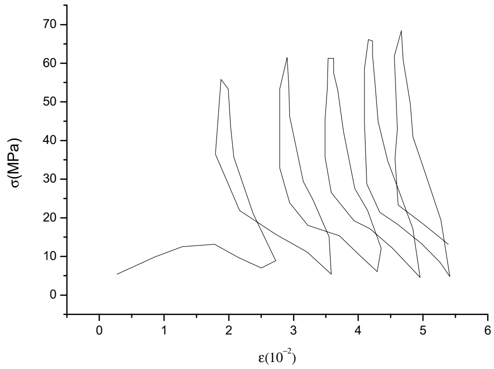

Figure 5: Stress-strain curve.

3 INFLUENCE OF SUBSTRATE MATERIAL ON THE THERMAL FATIGUE LIFE OF LCCC SOLDER JOINTS

3.1 Thermal Fatigue Life Prediction by LCCC Model

Critical weld joint thermal fatigue life calculation using Engel-maier modified Coffin-Mason equation for :

$$N_f = \frac{1}{2}\left(\frac{\Delta\gamma}{2\varepsilon_f}\right)^{\frac{1}{c}} \quad (1)$$

$$c = -0.442 - 6\times10^{-4}T_S + 1.74\times10^{-2}\ln\ (1+f) \quad (2)$$

$$\Delta\gamma = \sqrt{3}\,\Delta\varepsilon \quad (3)$$

N_f is average thermal fatigue life, $\Delta\gamma$ is equivalent shear strain range; ε_f is fatigue toughness coefficient of 0.325, f is cycling frequency of 24 weeks/day, $\Delta\varepsilon$ is equivalent plastic strain range.

The above parameters are substituted into equation (2) to calculate c = -0.3995, and the above parameters are substituted into equation (1) to calculate $N_f \approx 635$.

3.2 Influence of PCB Substrates on the Thermal Fatigue Life of Solder Joints

Considering the large stress-strain caused by the large difference in thermal expansion coefficient between the LCCC package material and the FR4-based PCB, the welding substrate was replaced with Al_2O_3 of the same material as the LCCC package, and the rest of the material parameters were kept unchanged, and the corresponding finite element model was established for analysis. From Figure 6 can be obtained from the key solder joints maximum equivalent plastic strain maximum value of 0.04877.

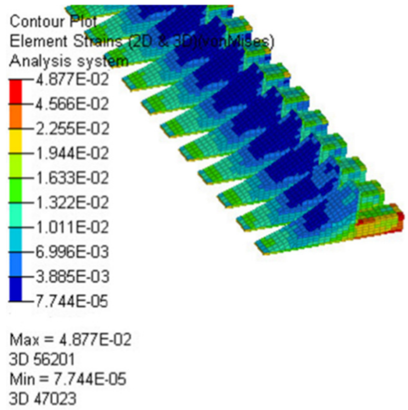

Figure 6: Maximum equivalent shaping strain of ceramic substrate.

The stree-strain curve for a solder joint with Al_2O_3 as the substrate is shown in Figure 7. From the figure it can be seen that the strain range of the solder joint within one temperature cycle is $\Delta\varepsilon = 0.0192$.

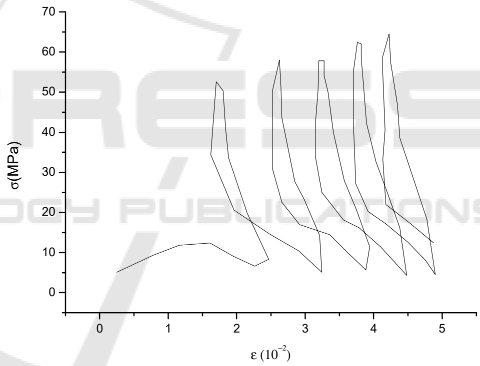

Figure 7: Stress-strain curve.

Bring the parameters into equation (1) and the thermal fatigue life $N_f \approx$ 852 was calculated for the LCCC encapsulated device with Al_2O_3 as the substrate, which is better than the thermal fatigue life of the LCCC encapsulated device with FR4 as the substrate.

4 CONCLUSIONS

The results of the analysis show that the highest stress strain is applied to the sharp corners of the LCCC package, where the solder joints are the first to fail.

Compared to FR4 substrate printed boards, using Al_2O_3, which is the same material as LCCC package, as the substrate can effectively improve the thermal fatigue life of solder joints under thermal cyclic loading conditions.

In the actual application of LCCC package devices, the devices can be soldered to the Al_2O_3 material adapter first, and then the adapter is soldered to the printed circuit board with a highly reliable connection such as through-hole soldering to improve the thermal fatigue life of LCCC package devices.

REFERENCES

Gao, L., Li, C., and Wan, P., (2017). A Superior Interfacial Reliability of Fe-Ni UBM During High Temperature Storage.*Journal of Materials Science:Materials in Electronics*, 28（12):8537-8545

Gao, L., LIU, Z.and LI, C.,(2017). Failure Mechanisms of SAC/Fe-Ni solder Joints During Thermal Cycling .*Journal of Eletronic Materials*, 46（8):5338-5348.

Hou, C., Tong ,J. and Rong, K. , (2014).Thermo-fatigue life study on LCCC electronic packaging structure. *structure & environment engineering*, 41（3）: 51-57.

Lall, P., Islam, M.N. , and Singh, N. (2004). Model for BGA and CSP reliability in automotive under hood applications. *IEEE Transactions on Components & Packaging Technologies*, 27（3）: 585-593.

Wei, H., Huang, C., and Liang, Y. , (2013) .Reliability analysis of plastic ball grid array double-bump lead-free solder joint under thermal cycle. *transactions of the china welding institution*, 34（10）: 91-95.

Zhang, X ., and Lee, S.W. , (2000) .Thermal fatigue analysis solder joints. *Journal of Electronic Packaging*, 122(3):200-206.