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The Effect of Solder Paste Volume on Chip Resistor Solder Joint Fatigue Life

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Abstract

The solder joint topology plays a significant role in determining its fatigue life. Due to the complex nature of the actual manufacturing environment, there are variations in solder volume for each joint, which can induce the solder shape variations and misalignment of the chip resistor. The solder shape variation can severely affect its fatigue life. In this study, we use surface evolver software to calculate the solder shape with the global minimum energy. A finite element method was used to model the resistor solder joint under thermal cycling and to predict the fatigue life for different solder paste volumes. Through varying the solder past volume to obtain different solder joint shape, the corresponding fatigue life was predicted. The result could provide a guideline for an/the choosing optimal solder paste volume for surface mount components. Analysis results show that a larger and balanced solder volume can give the best fatigue life under thermal cycling conditions.

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Keywords: Self-alignment, Solder Paste Volume, Solder Shape, Fatigue Life

1. Introduction

Numerous components are assembled in the SMT (Surface Mount Technology) production line. The solder joint reliability of the SMT component is a major concern; it is critical to understand the factors that affect the solder fatigue life of SMT components. As the solder volume measurement and inspection system integrated into the production line, the demand of the relation of the solder paste volume to its fatigue life arises. Qualification of SMT electronic components includes thermal cycling to estimate the solder fatigue life of the components. Each thermal cycle may take one hour and may require thousands of cycles until failure that depends on the product specification. The

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miniaturization of the SMT component and the time-consuming qualification process make it difficult to use an experimental method, so the finite element numerical simulation has been widely used.

There is a considerable amount of research that concentrates on the solder fatigue life estimation of the SMT components such as the chip resistor. Lu et al. divide the solder fatigue life into the portion between the termination and the pad and the portion at the fillet. They found the first portion will fail much faster than the second portion. [1], [2] It is well known that by increasing the standoff height, the solder fatigue life underneath the termination can be increased. [3] However, there is still controversy about calculating the solder fatigue life at the fillet portion. [1], [4]

In recent years, the surface evolver was adopted to predict a more realistic solder shape, so that a more accurate solder fatigue life can be acquired/obtained. [5] However, a/the rare research attempt was found to correlate the solder paste amount directly to its fatigue life.

In this study, a systematic methodology that uses a chip resistor as a test vehicle was established to correlate the solder paste volume to its fatigue life. By varying the solder paste amount, the final shape of the solder is predicted by the surface evolver based on the energy minimization principle. Then the actual solder shape that uses an energy-based method is imported into Ansys to predict its fatigue life using an energy-based method.

2. Experiment

2.1. Specimen

The test vehicle used in this study is shown in Figure 1. This chip resistor assembly consists of an organic PCB, copper pad, SAC305 solder, termination, and a chip resistor. The sample dimensions are listed in Table 1.

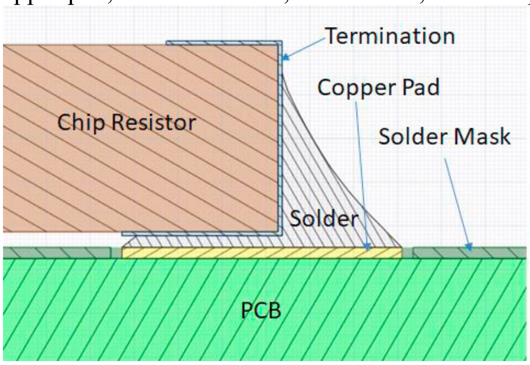

Figure 1. Schematic of Chip Resistor

Table 1. Sample Dimension

Item	Dimension (mm)
Chip Resistor	$1 \times 0.5 \times 0.35$
Termination Thickness	0.007
Copper Pad	$0.56 \times 0.5 \times 0.02$
Solder Mask Thickness	0.02
PCB	$3.42 \times 2.56 \times 1.58$

2.2. Material property

Dynamic mechanical analysis (DMA) system is utilized to characterize moduli of the PCB. The measurement result is shown in Figure 2. A size of $20 \times 3.0 \times 1.58\ mm^3$ $(L \times W \times T)$ test specimen is cut from the test vehicle PCB and put into the DMA. 0.1% strain was applied with 1 Hz frequency in a three-point bending test. The generated storage modulus data is used as the temperature-dependent elastic modulus applied into the simulation. The CTE of the PCB is measured by 3D digital image correlation (DIC). The DIC is a photogrammetry measurement technology with noncontact and full-field measurement capability. Both the in-plane and out-of-plane deformation can be characterized from correlating the successive images of samples at the initial and the deformed status.[6], [7] Its measurement sensitivity depends on the field of view and calibration deviation. The sensitivity in this measurement is ± 1.33 μm. By calculating the slope of the strain versus the temperature plot, the CTE of the PCB can be determined and its result is shown in Figure 3. The rest of the material of the test vehicle is from the vendor datasheet and is listed in Table 2.

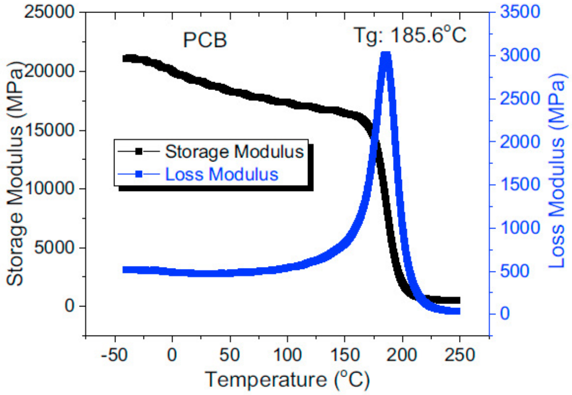

Figure 2. PCB modulus measurement result

Table 2. Material Properties

Materials	Young's Modulus (GPa)	Poisson's Ratio	CTE (ppm/°C)
Resistor	282.7	0.22	6
Termination	83	0.37	18.9
Solder	28-48	0.4	21.7
Copper	121	0.35	17
Solder Mask	2.4	0.3	60-160

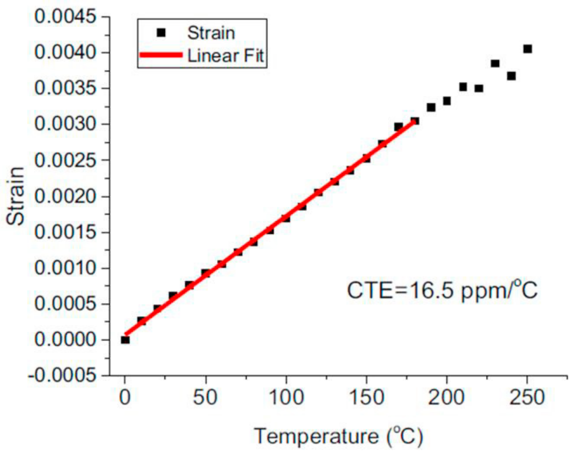

Figure 3. PCB CTE measurement result

3. Simulation

3.1. Surface evolver solder shape prediction

In the SMT reflow soldering process, the gravity together with the surface tension of the molten solder play an important role in the final solder shape. To achieve balance when the solder wets the copper pad, the pad, molten solder, and the lead are in the steady state energy minimization based on the energy minimization principle. The total energy E equals to surface potential energy E_s plus gravitational potential energy E_g. The actual final shape of the solder can be determined through minimizing/the minimization of the total energy in surface evolver,.[8] In order to analyze the solder amount's effect on the solder fatigue life, various initial solder volumes are used in the model to a generate different solder shape model. The standard solder volume is set as 100%; solder volume from 50% to 150% is also used in the model. The design of experiment of the solder volume is shown in Table 3. The corresponding solder shape was shown in Figure 4.

Table 3. Design of Experiments

Cases	Left-side solder volume (%)	Right-side solder volume (%)
Balanced 1	50%	50%
Balanced 2	100%	100%
Balanced 3	150%	150%
Unbalanced 4	50%	100%
Unbalanced 5	50%	150%
Unbalanced 6	100%	150%

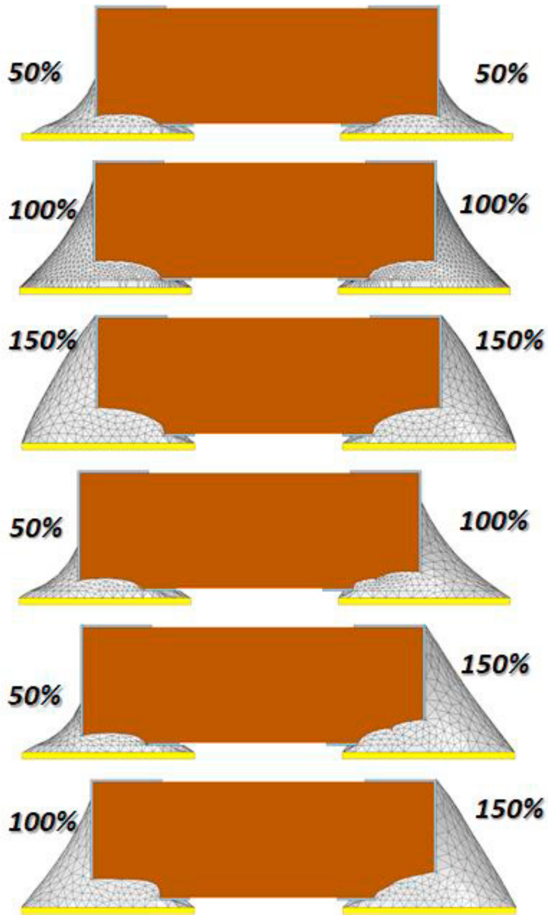

Figure 4. Solder Shape with Different Volume

3.2. Finite element model

Based on the surface evolver model, the copper pad, PCB, and solder mask are added to complete the model for structure analysis, shown in Figure 5. Due to the symmetry reason, quarter models are used for balanced cases while half models are used for unbalanced cases. The model is set to go through thermal cycling loading between -55˚C to 125˚C, 40 min per cycle as shown in the temperature profile Figure 6. The ramp time is set to 10 min and the dwell time is also 10 min. The highest temperature 125˚C was set as the reference temperature. The/An Anand model with nine constants is adopted here to represent the viscoplastic behavior of the SAC305 solder.[4] Darveaux's model is used to calculate the solder fatigue life.[9] The total solder fatigue life FL is divided into two portions. The first portion, FL_1, is the fatigue life of the solder in between the termination and the copper pad, shown in Figure 7. This thin layer of solder bears most of the thermal mechanical load and will fail first. The second portion, $FL_{2,}$ is the fatigue life of the solder at the fillet part. In order to shed some light on which path the crack will most likely take at the fillet portion, 0˚, 30˚, 45˚, 60˚ and 90˚ path strip are defined (shown in Figure 7) and each path fatigue life is calculated individually. The smallest solder fatigue life will be utilized as the fillet portion FL_2 and the corresponding path is the one the crack will take.

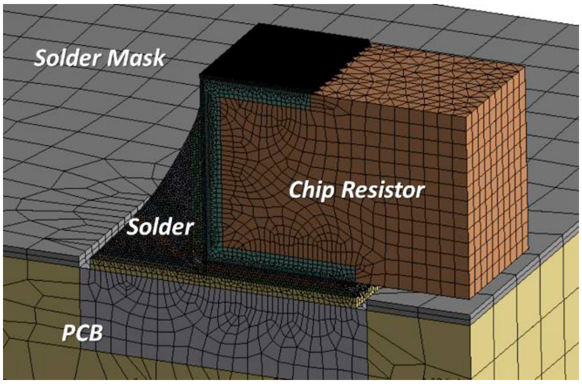

Figure 5. Meshed Quarter Model

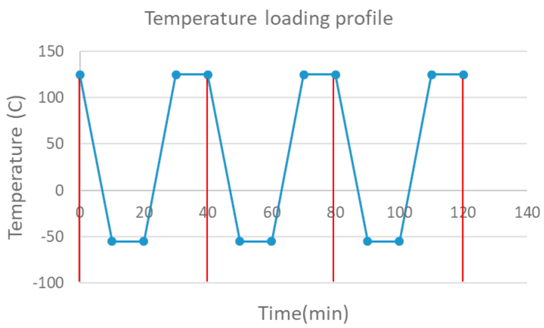

Figure 6. Thermal Cycling Temperature Profile

3.3. Solder fatigue life prediction

Darveaux proposed the correlation between solder fatigue life and inelastic energy in solder joint subjected to thermal cycling for SAC alloy, shown as follows:

$$\Delta W_{ave} = \frac{\sum(\Delta W \times V)}{\sum V}$$
$$N_0 = K_1(\Delta W_{ave})^{K_2}$$
$$\frac{da}{dN} = K_3(\Delta W_{ave})^{K_4}$$
$$\alpha = N_0 + \frac{a}{da/dN}$$

Where ΔW is the accumulated plastic work of volume V per cycle, N_0 is the number of cycles it takes to start crack propagation, which is usually neglectable, a is the crack length, N is the number of cycles it takes from crack propagation to failure, α is the total fatigue life, and K_1, K_2, K_3, K_4 are fitting parameters. In this study, the fitting parameters are from literature.[9] The crack length a is measured from the model. ΔW will be stable after three thermal cycles in the simulation. The plastic work accumulated in the third cycle will be used to predict the fatigue life. The intact model will be run first to get the FL_1 portion fatigue life. Then the solder between the termination and the copper pad will be taken off to run thermal cycling to get the fillet portion solder fatigue life FL_2.

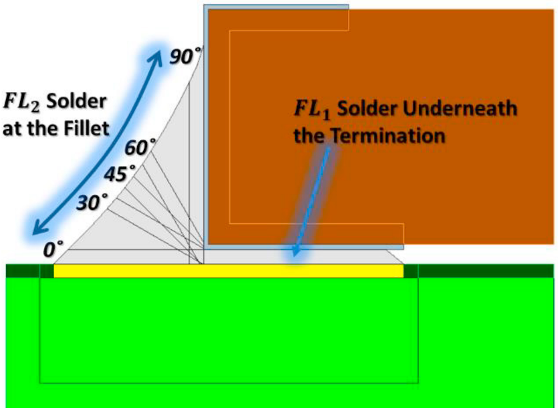

Figure 7. Volumes for Average Plastic Work Calculation

4. Result and discussion

4.1. Fatigue life of the v1 portion

The calculated fatigue life FL_1 is shown in Figure 8. For the balanced volume model, the average plastic work and crack length are similar to each other, which results in similar fatigue life. The larger volume case has a slightly smaller fatigue life. This could be attributed to a larger constraint introduced by a larger fillet. For the unbalanced volume model, less solder volume side fatigue life is always larger than larger solder volume side. There are two reasons for this phenomenon. The first one is that due to the larger solder volume pushing the resistor to the smaller side, the solder amount of this portion is larger on the smaller solder volume side. The second one is that due to less constraint of the smaller fillet, the smaller side average plastic work is 15% less than the larger solder volume side.

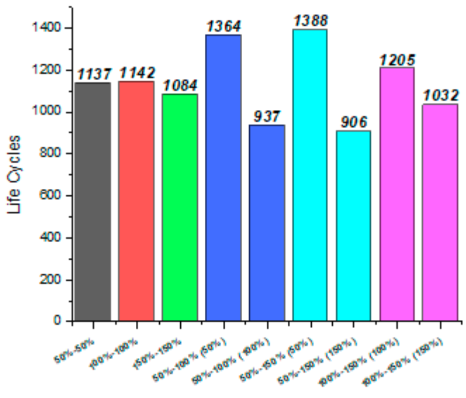

Figure 8. Life Cycle for Solder Underneath the Termination

4.2. Fatigue life of the fillet portion

Figure 9 shows the fillet portion solder fatigue life versus the crack path angle for the balanced model. For the 50% solder volume case, the crack is likely to take a/the 30˚, 45˚, 60˚path. For the 100% solder volume case, the crack is more likely to take a/the 30˚, 45˚ and 90˚ path while the 60˚ path is also possible. For the 150% solder volume case, the crack is more likely to take a/the 90˚ path while a/the 30˚ path is also possible. Figure 10 shows the fillet portion solder fatigue life versus path angle for the unbalanced model. For the 50%-100% and 50%-150% solder volume cases on the less solder side, the crack is more likely to take a/the 30˚, 45˚, 60˚path while the 90˚ path is also possible. For the 100%-150% solder volume case on the less solder side, the crack is more likely to take a/the 30˚, 45˚, 90˚ path while the 60˚ path is also possible.

4.3. Total solder fatigue life

The total solder fatigue life FL is calculated by adding fatigue life of the solder underneath the termination FL_1 and the fatigue life of the fillet solder FL_2, as shown in Figure 11. In the balanced model, the solder fatigue life increases as an increasement of the solder volume. In the unbalanced solder volume cases, the solder crack happens at the less solder side. In the mild unbalanced case, 50%-100% fatigue life cycles fall between the 50%-50% case and the 100%-100% case. A similar phenomenon happens to a/the mild unbalanced case 100%-150%, in which fatigue life falls between the 100%-100% case and the 150%-150% case. In the severe unbalanced solder volume case 50%-150%, solder fatigue life is close to the 50%-50% case. The overall unbalanced cases' solder joint fatigue life tends to be restricted by its less solder paste volume side.

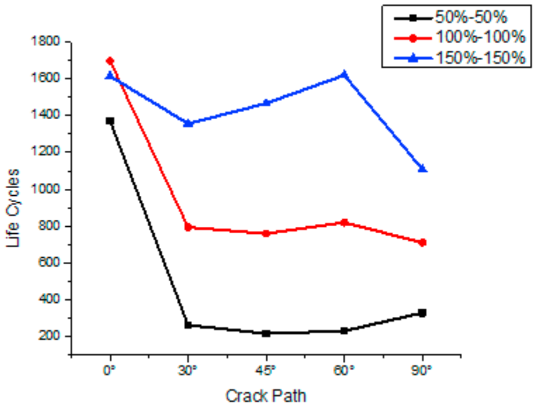

Figure 9. Life Cycles for Balanced Model Fillet Solder

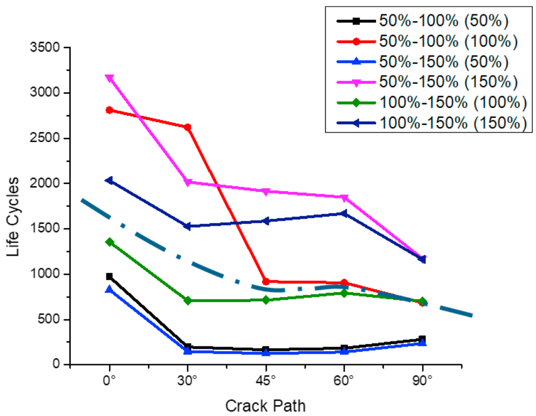

Figure 10. Life Cycles for Unbalanced Model Fillet Solder

5. Conclusion

In this work, the systematic solder fatigue life prediction methodology is established for chip resistor assembly for various solder paste volumes. Material properties of PCB are characterized by DIC and DMA. Based on the/an energy minimization principle, a more realistic solder shape is predicted by a/the surface evolver. Solder crack path is predicted for different cases. The simulation result suggests that more solder paste will result in more solder fatigue life. Severe unbalanced solder paste volume on two sides of the chip resistor should be avoided.

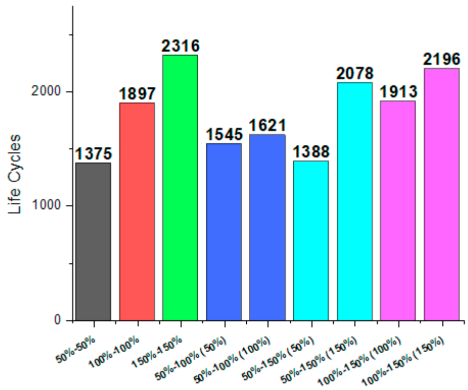

Figure 11. Total Solder Fatigue Life

References

[1] J. Nottay, M. Dusek, C. Bailey, H. Lu, and C. Hunt, "Modelling the fatigue life of solder joints for surface mount resistors," pp. 136–142, 2002.

[2] M. J. Rizvi, H. Lu, C. Bailey, E. Bevan, N. Pountney, and J. Coates, "Finite element modelling of failures in thick film chip resistor solder joints," *Int. Microsystems Packag. Assem. Circuits Technol. Conf. IMPACT 2010 Int. 3D IC Conf. Proc.*, pp. 2–5, 2010.

[3] C. J. Zhai, S. Sidharth, R. Gannamani, R. C. Blish, and R. N. Master, "Design and process optimization for reliable resistor pack solder joints for microprocessor packages," pp. 1129–1135, 2004.

[4] C. Han and B. Han, "Board level reliability analysis of chip resistor assemblies under thermal cycling: A comparison study between SnPb and SnAgCu," *J. Mech. Sci. Technol.*, vol. 28, no. 3, pp. 879–886, 2014.

[5] Z. Guanqun and W. Chunqing, "Shape and fatigue life prediction of chip resistor solder joints," *2009 Int. Conf. Electron. Packag. Technol. High Density Packag. ICEPT-HDP 2009*, vol. 0, pp. 1167–1170, 2009.

[6] S. Shao, P. Shang, C. Zhong, H. Wang, S. Park, and V. Pham, "Quantification of Underfill Influence to Chip Packaging Interactions of WLCSP," p. V001T01A004, 2018.

[7] Y. Niu, J. Wang, S. Shao, H. Wang, H. Lee, and S. B. Park, "A comprehensive solution for electronic packages' reliability assessment with digital image correlation (DIC) method," *Microelectron. Reliab.*, vol. 87, no. June, pp. 81–88, 2018.

[8] K. Pan, H.Y. Wang, J.H. Ha, I. Parviziomran, D. H. Won, S.B. Park, "The effect of solder paste volume on surface mount assembly self-alignment"

[9] R. Darveaux, "Effect of simulation methodology on solder joint crack growth correlation," *Proc. - Electron. Components Technol. Conf.*, pp. 1048–1058, 2000.