

The Mechanism of Solder Cracking

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Soldered jointings are indispensable to high-density surface mounting of electronic equipment. Maintaining the reliability of soldered jointings is going to become a major problem that must be overcome to accurately mount miniaturized electronic parts. These soldered jointings deteriorate with exposure to long-term heat and mechanical stress, causing cracking which leads to part failure. In this paper we shall report on reliability testing to confirm the mechanism of solder cracking due to heat stress.

1. Introduction

Many problems exist in relation to soldering reliability, but in this report we shall deal with analyzing the solder cracking mechanism caused by heat cycles. Improving reliability has become vital due to the increase in the number of soldered jointings and recent high-density surface mounting.

When observing a cross section of solder cracking that generally occurs in the field, we can confirm that the particles of each phase of Sn (tin) and Pb (lead) have roughened when compared to the initial soldered jointings. This roughening phenomenon can be confirmed by heating solder to high temperatures and by storing long-term at room temperature.¹⁾ Furthermore, in cracking occurring in a jointing interface with Cu (copper), only Pb leaves any significant residue on the jointing interface. This is because at high temperatures the dispersing of Sn toward Cu is accelerated, and only Pb remains on the jointing surface, causing a degradation of jointing strength. Considering these factors, we performed the High Temperature Storage Test, the Temperature Cycle Test (air chamber method), and the Thermal Shock Test (liquid bath method) to investigate the effects of high temperatures, and the effects of heat stress due to the temperature cycle.

We would like to report our confirmation of the solder cracking mechanism. According to the results of those tests, the crystallization of solder is changed by heat and stress, resulting in the degradation of mechanical characteristics.

2. Solder and Solder Cracking

Solder is an alloy of Sn (tin) and Pb (lead). This combination forms a eutectic alloy particularly well-suited to jointing due to such characteristics as viscosity, flowability, and melting point. When solder is cooled from the liquid phase and reaches crystallization point, it crystallizes in two solid phases, the Pb-rich α phase, and the Sn-rich β phase.²⁾ Immediately after the jointing solidifies, these two phases are uniformly distributed as small particles. When the jointing is with Cu, such as a printed circuit board pattern, the Sn in the solder is dispersed (intergranular dispersion) within the Cu granular boundary, and forms a jointing by making an intermetallic compound. This solder jointing deteriorates due to long-term heat and mechanical stress, resulting in such phenomena as solder cracking. (Photo. 1, a and b). To confirm this failure mechanism, we performed reliability testing on the effects of heat stress.

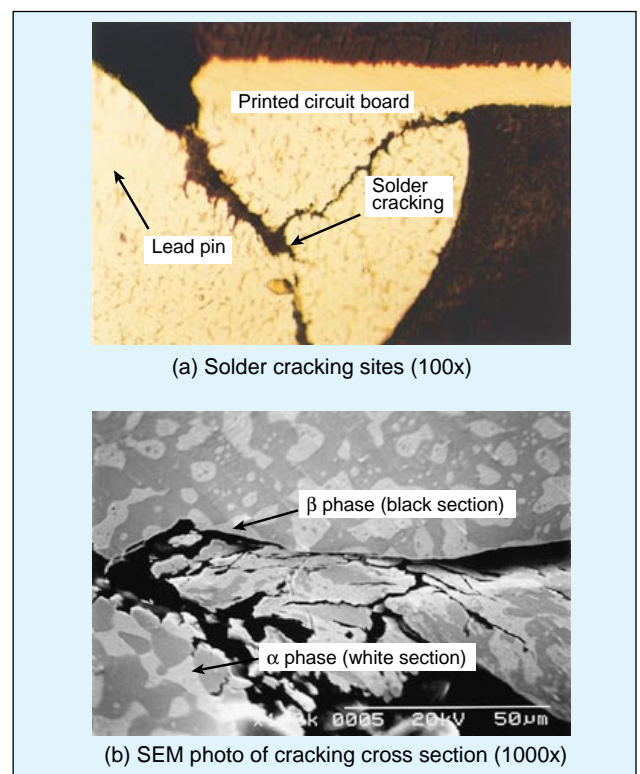


Photo. 1 Cross sectional view of solder cracking

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3. Reliability Testing Results

Table 1 shows testing conditions. A phenol substrate board with one paper surface was used as a specimen. Testing was begun by dipping a lead pin section with copper covered with Sn or solder plating in solder (63 Sn wt%) at 260°C for 10 seconds. After testing, solder cracking sites were impregnated with resin, cross sectioned, polished, and then observed under an SEM (Scanning Electron Microscope).

Table 1 Test items and test conditions

Test Items	Test Conditions
High Temperature Storage Test (Using Tabai High Temperature Chamber model PHH-200)	125°C, 100 hours
	150°C, 100 hours
Temperature Cycle Test (Using Tabai Air-to-Air Thermal Shock Chamber model TSA-70H)	-65°C ↔ +125°C, 500 cycles, 30 minutes each
Thermal Shock Test (Using Tabai Liquid-to-Liquid Thermal Shock Chamber model TSB-5)	-65°C ↔ +125°C, 500 cycles, 5 minutes each

*Each test name uses EIAJ standards.

3-1 Results of High Temperature Storage Test

Specimens were left under high temperature for either 48 or 100 hours, then removed, cross sectioned, and observed. Results of the observation indicated that under conditions of 150°C for 48 hours the α phase showed considerable progression in roughening. Observation after 100 hours at 125°C showed that roughening progression had continued. (Photo. 2) From these results we were able to confirm that long-term exposure to high temperature promotes roughening of the α phase.

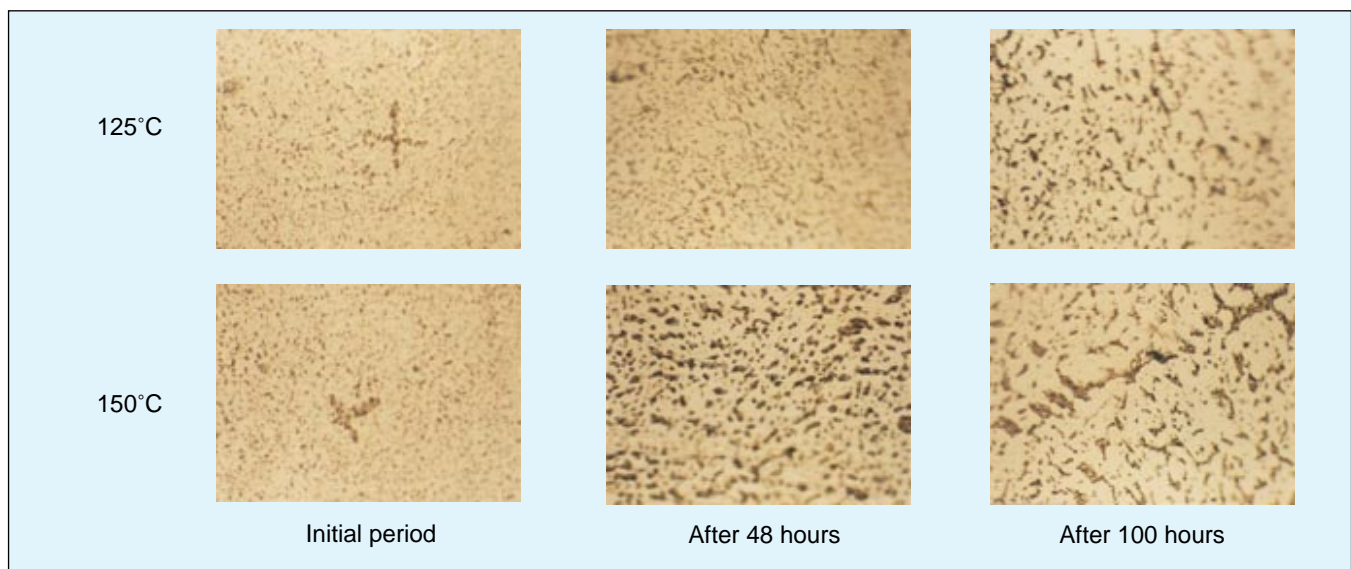


Photo. 2 Changes in the α phase during the High Temperature Storage Test (500×)

3-2 Results of Temperature Cycle Test

Cracking occurred as in Fig. 1 in the vicinity of the substrate pin hole (section a) and near the lead pin (section b). Using the SEM to observe the section with cracking showed that roughening had occurred in the α phase, and that those particles had taken a grain-oriented configuration. (Photo. 3) Investigating the cross sectional surface of the cracks revealed surface breaking that showed signs of high stress having been applied, particularly in the surface fractured from the α phase section. In addition, in the α phase some sections that have not cracked show a number of micro cracks. (Photo 4)

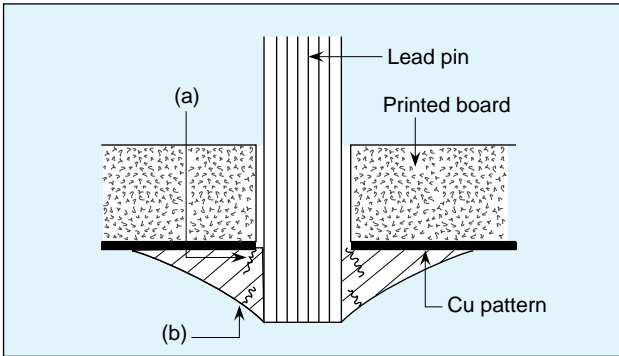


Fig. 1 Cracking sites resulting from the Temperature Cycle Test

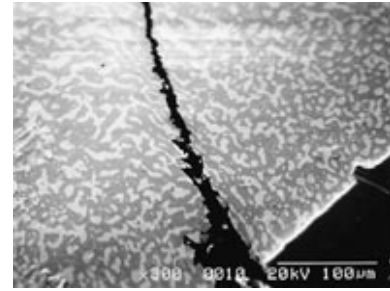


Photo. 3 Cross section of crack break (300x)

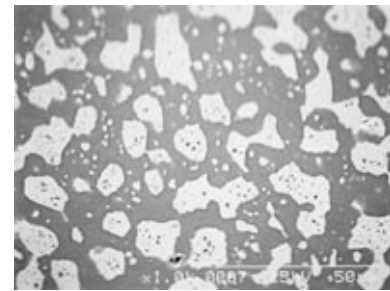


Photo. 4 Micro cracks in the α phase (1000x)

3-3 Results of the Thermal Shock Test

A few cracks can also be found in the internal section of the solder, but as seen in Fig. 2, these are at sites where the solder adjoins the lead pin (section a) or the Cu pattern (section b) and are due to separation of the interface. (Photo. 5) In addition, this intermetallic compound alloy has become thickened, and we can assume that the dispersion of Sn has progressed. Unlike the Temperature Cycle Test, no micro cracking occurred.

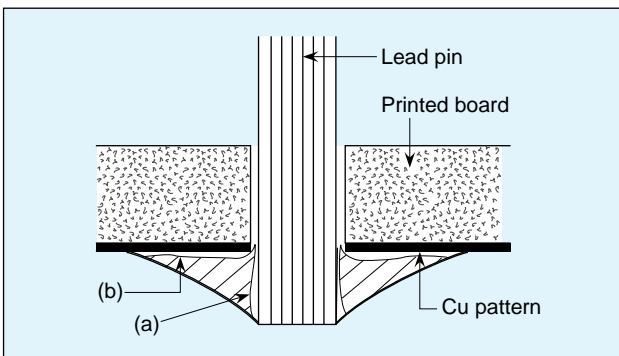


Fig. 2 Checking sites due to the Thermal Shock Test

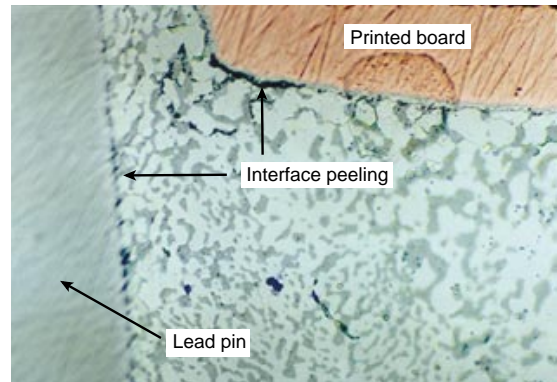


Photo. 5 Cross section of interface peeling (200x)

4. Discussion of the Solder Cracking Mechanism

In general, the crystalline (eutectic) condition of the solder jointing sections is in the form of small particles in the initial period after the solder is applied. This condition excels in mechanical characteristics, and softens in response to stress, but if left a long time, melting and dispersal gradually occur, and the particles get larger. High temperature and stress promote this dispersal. Solder that has undergone these changes has experienced degradation of its mechanical characteristics. In other words, this solder performs with the individual characteristics of Sn and Pb.^{1), 5)}

Using Table 2 to compare the characteristics of Sn and Pb with solder shows that both their shear force and tractive force are considerably less. Also, the grain boundary in each phase is rougher, so the intergranular junction surface becomes broader. At this point, repeatedly applying strong stress causes cracking. Below, we shall discuss this cracking process as it occurs in the Temperature Cycle Test and the Thermal Shock Test.

Table 2 Characteristics of solder Sn and Pb ^{3), 4)}

Characteristics	Unit	Solder 60 Sn wt%	Sn	Pb
Tractive force	kg/mm ²	5.4	1.5	1.4
Shear force	kg/mm ²	3.47	2.02	1.39
Stretching	%	30	55	39

4-1 Cracking Mechanism in the Temperature Cycle Test

- 1) When leaving at high temperature, the dispersion of Sn progresses, and α phase (Pb) roughening occurs.
- 2) The temperature cycles apply repeated stress to the solder jointings due to the differences in the heat expansion coefficients of solder, the lead pin, and the printed circuit board.
- 3) The α phase undergoes elongation stretching in the direction of stress, and micro cracking occurs to alleviate the stress.
- 4) Because the grain boundary in each phase is rougher, the joining strength of the Sn and Pb jointing interface deteriorates in response to stress.
- 5) Because of this, the grain boundary ruptures, after which micro cracking occurs, causing degradation of the shear force, and the solder cracking phenomenon can be seen in the α phase as well. (Fig. 3)

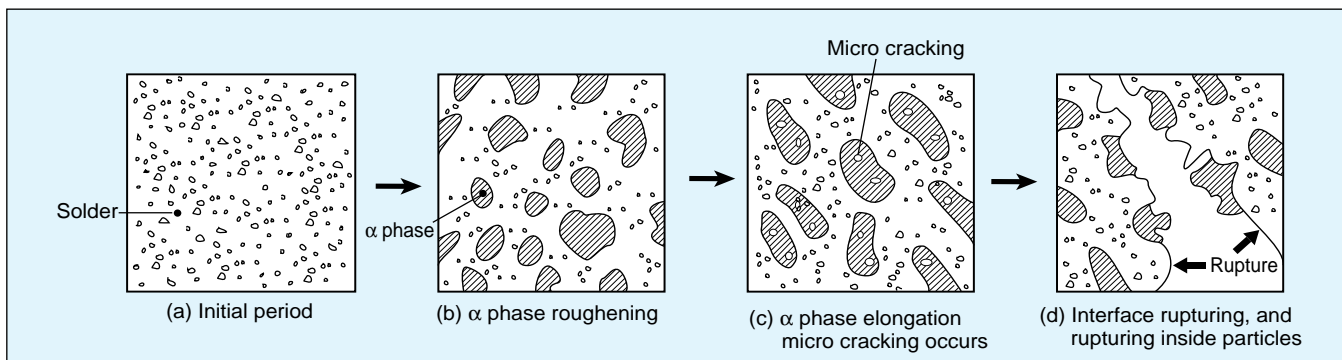


Fig. 3 Cracking process caused by Temperature Cycle Test

4-2 Cracking Mechanism in the Thermal Shock Test

- 1) The thermal conductivity of the liquid medium is higher than in the air chamber method, so under high temperatures the dispersing of Sn toward metals such as Cu progresses, and the surface of the intermetallic compound (Cu-Sn alloy) is in the α phase (Pb).
- 2) The temperature cycles apply repeated stress to the solder jointings due to the differences in the heat expansion coefficients of solder, the lead pin, and the printed circuit board.
- 3) Due to the abrupt temperature changes, strong stress is applied to the α phase of the intermetallic compound, and rupturing and interface peeling occur. (Fig. 4)

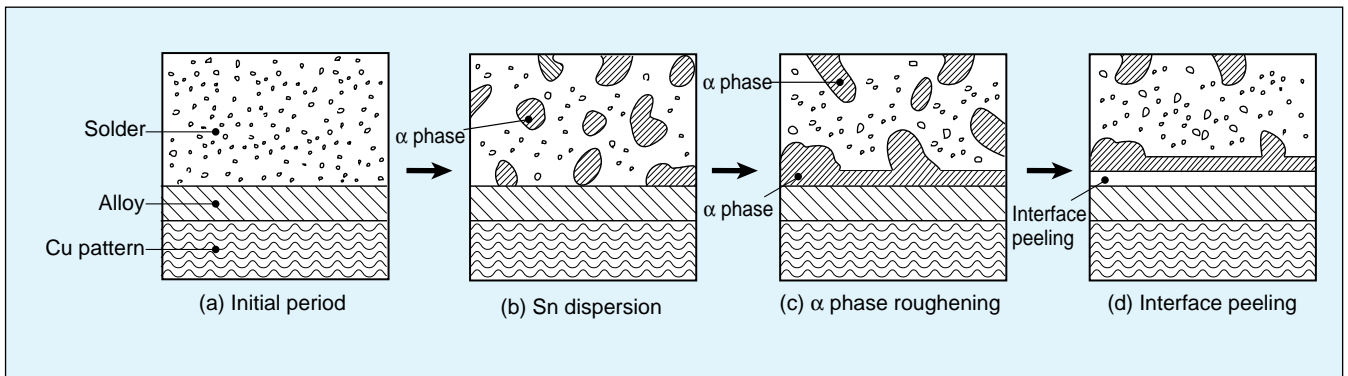


Fig.4 Cracking process caused by Thermal Shock Test

5. Conclusion

In this report, we have presented our findings on the solder cracking mechanism due to heat stress. These results indicate that the Temperature Cycle Test (air chamber method) and the Thermal Shock Test (liquid bath method) are effective methods of evaluating solder reliability. However, since the failure modes differ, we can assume that the evaluation points also differ.

- 1) Temperature Cycle Test (air chamber method)
Cracking occurs inside the solder, and this test is an effective method of evaluating degradation of solder characteristics.
- 2) Thermal Shock Test (liquid bath method)
Cracking occurs on the PCB pattern and soldered jointings of lead pins, and this test is an effective method of evaluating the condition of the soldered junction.

[Reference Bibliography]

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