Report 1

Confirming Reliability of Printed Circuit Boards with Temperature Cycle and Thermal Shock

Hirokazu Tanaka*/ Yuuichi Aoki*/Shigeharu Yamamoto*

Ahanges in our modern way of life have fostered the miniaturization of electronic appliances and their use in a wide variety of environments. This miniaturization of electronic appliances has increased the mounting density of PCB (printed circuit boards) and has narrowed the tolerance between conductors to minute gaps. On the other hand, the diversity of environments in which this equipment is used has brought on numerous types of environmental stress to PCBs. When heat stress and mechanical stress are applied to the minute gaps between conductors, such stress causes openings in the wiring pattern and results in part failure.

In this report, to confirm the effects of heat stress on PCB through holes, we performed the Temperature Cycle Test (air chamber method) and the Thermal Shock Test (liquid bath method). As a result, we found a strong relationship between solder cracking and the life of the copper-plated through hole. In addition, we shall report on our confirmation of the mechanism leading to that failure life.

1. Introduction

The increasingly broad range of applications for electronic appliances has introduced PCBs into all sorts of fields where they are used under a wide variety of conditions. In addition, wiring patterns have narrowed and through holes have become smaller due to the miniaturization of on-board parts, as well as high-density surface mounting. These factors make maintaining the reliability of PCBs increasingly vital.

In this article, we shall report on testing and analysis of degradation of PCB through holes due to temperature cycle and thermal shock.

2. Reliability and Test Method for Copper-plated Through Holes

The degradation of copper-plated through holes shows up as cracking and breaking in the plating caused by heat stress and mechanical stress.

During heat stress, the differences in thermal expansion in the various materials such as copper, the board (resin), and the solder bring repeated stress to bear on the copper-plated section.1), 2) For this investigation, we performed the Temperature Cycle Test (air chamber method) and Thermal Shock Test (liquid bath method). We analyzed the failure mechanism through changes in the characteristic values as well as through observation of cross sections.

The specimen for testing was a glass epoxy substrate board (USA NEMA standard No. FR-4) with continuously connected landless plated through holes as shown in Fig.1. Table 1 shows test conditions. The test investigated the changes in characteristic values and failure modes depending on the presence or absence of solder in the through hole, as well as the test temperature and temperature change time. Changes in the conductor resistance of the substrate board were measured with a milli-ohm meter. In addition, cross section observation was carried out by impregnating the through hole with resin, cross sectioning, and observing with a metallurgical microscope.

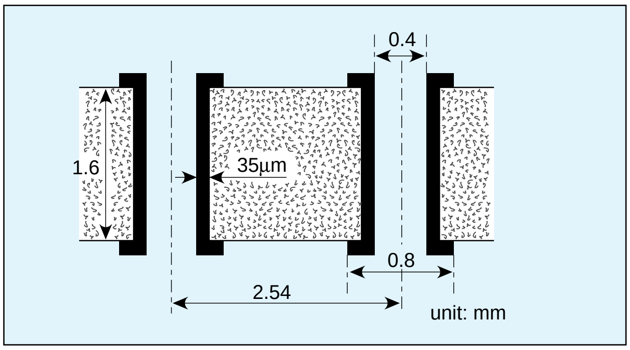


Fig. 1 Through hole shape

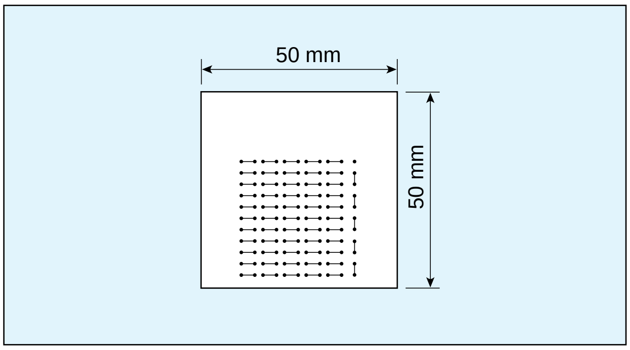


Fig. 2 Substrate board pattern

---

*Environmental Test Technology Center

Table 1 Test Conditions

Test Purpose	Test Items	Pretreatment	Test Conditions
Difference with or without solder	Temperature Cycle Test (air chamber method)	○	−65°C ↔ +125°C, 30 min. each, 1000 cycles
		×	
Difference due to temperature (with solder)	Temperature Cycle Test (air chamber method)	○	−40°C ↔ +125°C, 30 min. each, 1000 cycles
			−65°C ↔ +125°C, 30 min. each, 1000 cycles
			−65°C ↔ +150°C, 30 min. each, 1000 cycles
Difference due to temperature change time (with solder)	Temperature Cycle Test (air chamber method)	○	−65°C ↔ +125°C, 30 min. each, 1000 cycles
	Thermal Shock Test (liquid bath method)		−65°C ↔ +125°C, 5 min. each, 1000 cycles

*Pretreatment: solder heat resistance test, 260°C, 10 seconds, solder: 63 Sn wt%

3. *Test Results*

3-1 Differences With and Without Solder

Fig. 3 shows changes in through hole conductor resistance. The failure mode in both instances, determined through cross section observation, was found to be corner cracking of the copper plated section. Furthermore, degradation proceeded more rapidly with solder present, so we can assume solder is related to the progression of cracking. (Photo. 1)

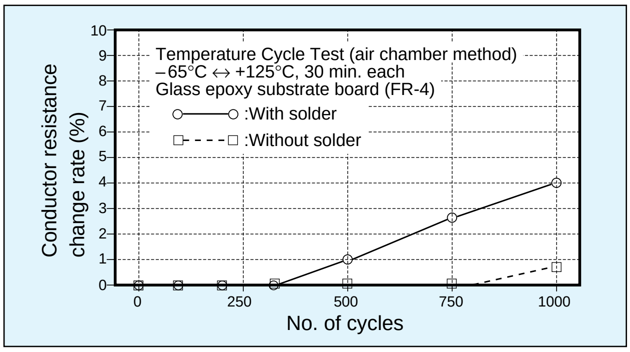
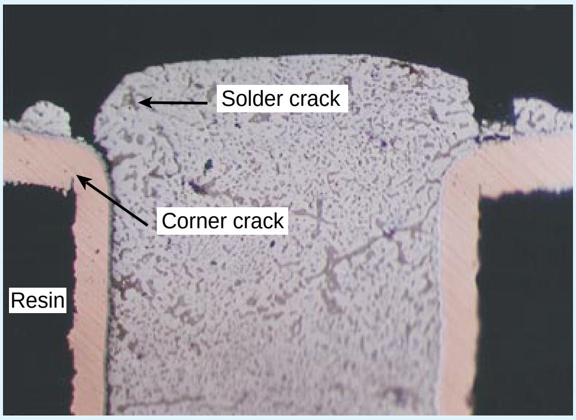


Fig. 3 Changes in conductor resistance with and without solder



Test conditions: Temperature Cycle Test
−65°C ↔ +125°C, 30 min. each, 500 cycles

Photo. 1 Cross section observation results (with solder) (200×)

3-2 Differences Due to Temperature Conditions

Fig. 4 shows changes in conductor resistance due to each temperature condition, and Photo 2 shows results of cross section observation occuring at 500 cycles under each set of conditions. The results confirm that the failure mode under each set of conditions is caused by corner cracking of the copper plated section, and that the greater the temperature difference, the faster the progress of the degradation.

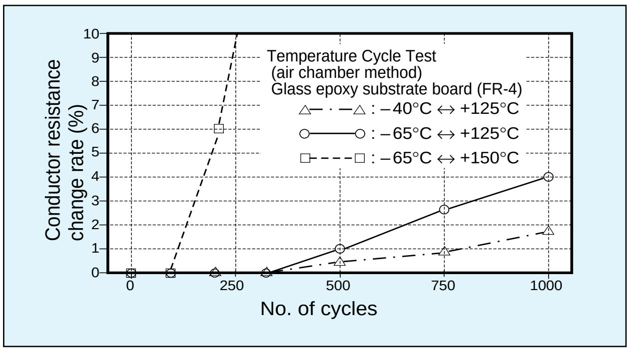


Fig. 4 Changes in conductor resistance for each temperature

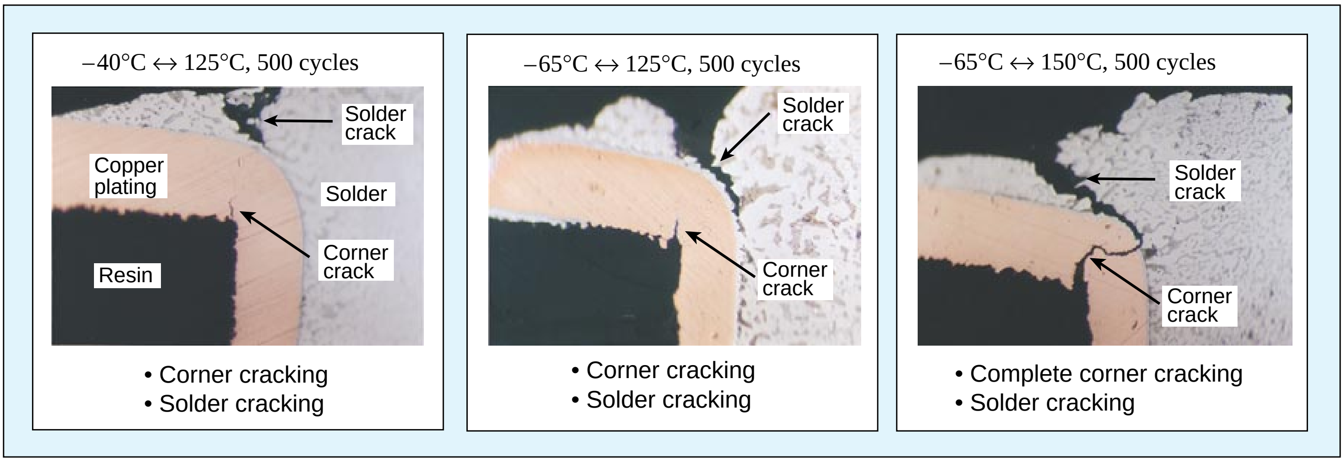


Photo. 2 Cross section observation results (500×)

3-3 Differences Due to Temperature Change Time

To compare differences caused by temperature change time, we performed the Temperature Cycle Test (air chamber method) and the Thermal Shock Test (liquid bath method). Fig.5 shows the change in conductor resistance values. Observing the cross sections indicates that the failure mode is corner cracking in both tests, but deformation of the copper plated section occurs in the Thermal Shock Test, leading us to assume strong stress. (Photo. 3)

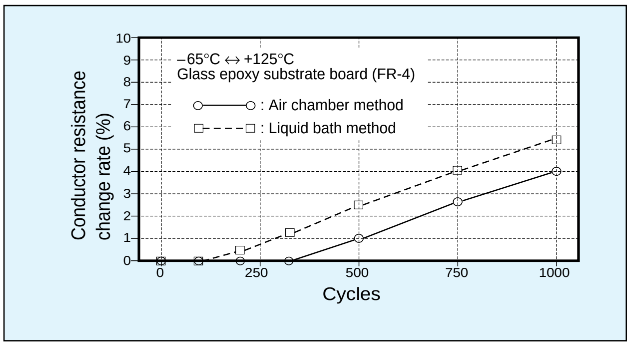
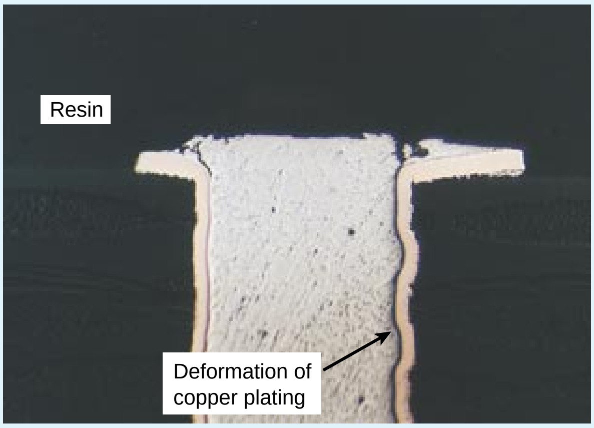


Fig. 5 Changes in conductor resistance due to air chamber method and liquid bath method



Test conditions: Thermal Shock Test
−65°C ↔ +125°C, 5 min. each, 1000 cycles

Photo. 3 Results of cross section observation (100×)

4. Discussion

In this series of testing, cross section observation clearly showed cracking occuring in the solder in cases of corner cracking of the copper plated through holes which broke completely through. Furthermore, in specimens in which the solder fillet (the solder section filling the junction angle) is high and solder cracking did not occur, corner cracking did not break completely through. From these results, we can assume that a strong relationship exists between solder and the life of copper plated through holes, and that by suppressing solder cracking, through hole reliability can be improved.

Table 2 shows the configuration of the printed circuit board and the coefficient of thermal expansion for each material. Differences in thermal expansion coefficients for the different materials causes stress in response to the temperature cycles to be concentrated on the solder and the corner sections as shown in Fig.6.[3] When strong stress is repeatedly applied in this area, cracking occurs. Furthermore, during the initial period, cracking occurs in the copper plating before occuring in the solder.

Table 2 Coefficient of thermal expansion for each material

Material	Coefficient of thermal expansion (ppm/˚C)
Copper	17
Solder	24 – 25
Glass epoxy (xy axis)	13 – 18
Glass epoxy (z axis)	110 – 250

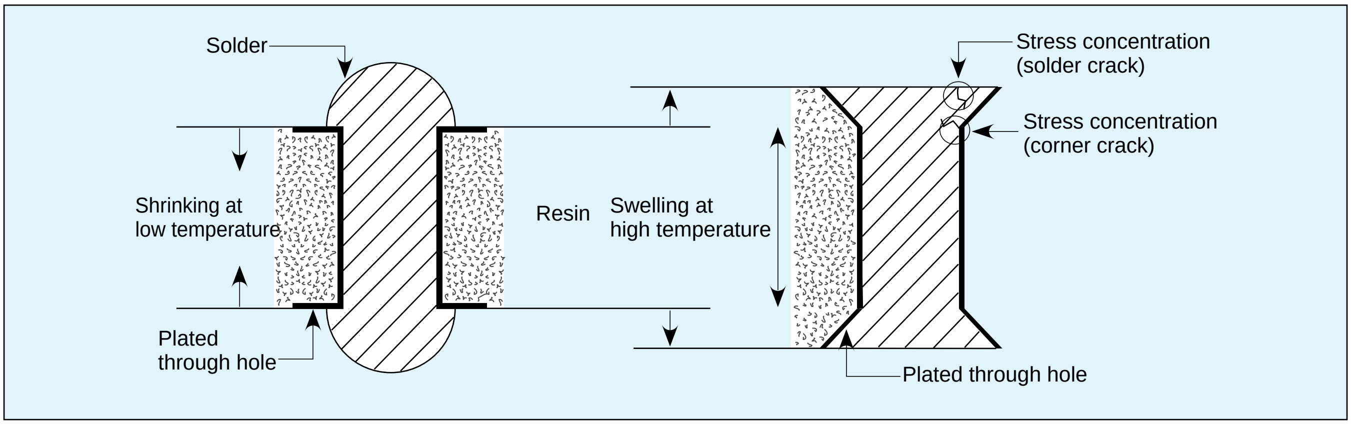
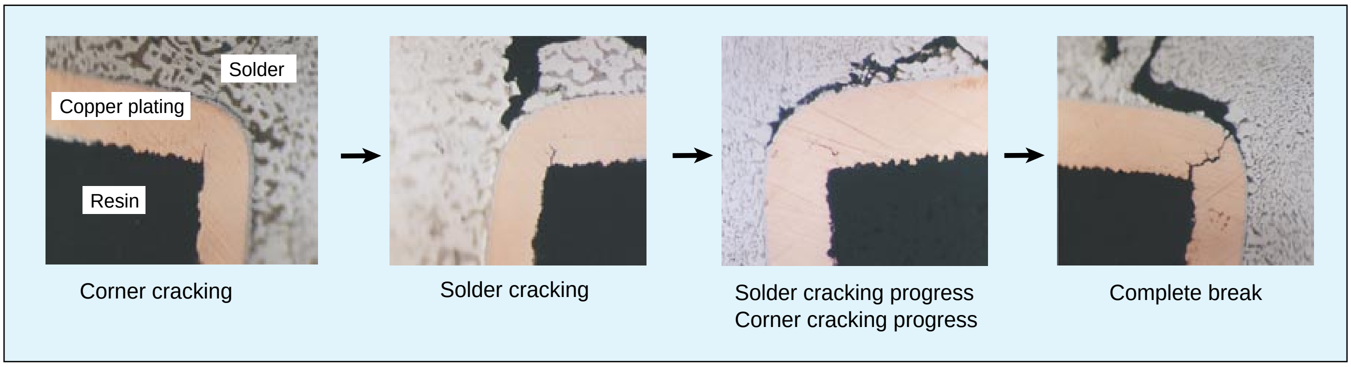


Fig. 6 Deformation of through hole due to temperature cycle

However, due to high temperature and stress the solder also sustains roughening of the intergranular boundary, loses shear force and tractive force, and finally ruptures. Then, the stress is concentrated in the corner, promoting cracking and leading to a complete break. Photo. 4 shows this process.



Corner cracking

Solder cracking

Solder cracking progress
Corner cracking progress

Complete break

Photo. 4 Corner cracking process (500×)

5. Conclusion

This investigation led to the following conclusions.

1) Failure of plated through holes on PCB is mainly due to corner cracking. This can be confirmed using the Temperature Cycle Test (air chamber method) and Thermal Shock Test (liquid bath method).
2) Corner cracking is strongly related to solder cracking, and so through hole reliability can be improved by suppressing cracking.
3) We were able to confirm that the greater the test temperature difference, and the faster the temperature change time, the faster the through hole degradation.

In this investigation, we were able to confirm through ross section observation that through hole degradation is related to solder cracking, but we have not yet been able to analyze the statistical data for the relationship.

Moreover, investigation must be continued to determine how through hole degradation and solder cracking are related to changes in conductor resistance.

[Reference Bibliography]

1) Seizo Tanaka, Tomoaki Shimizu: “Reliability Evaluation by Temperature Cycle Tests of Through-hole Boards”, Proceedings of the 11th. Union of Japanese Scientists and Engineers Symposium on Reliability and Maintainability (1981)
2) Masako Horimoto, Isao Akaishi, Tamotsu Ishikawa, Hirofumi Murata, Akio Yoshida (Matsushita Electronic Components Co., Ltd.): “A Study on a Method of Predicting the life of PTH”, Proceedings of the 22nd. Union of Japanese Scientists and Engineers Symposium on Reliability and Maintainability (1992)
3) Toshiki Sasabe (Digital Equipment Corporation Japan): “Plating Technology of Printed Wiring Boards”, Nikkan Kogyo Surface Mounting Technology (1993)