Investigation on the failure criterion of reliability testing for Pb-free BGA packages

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ABSTRACT

Daisy-chained test vehicles are commonly used in board level reliability testing. By continuously monitoring the in-situ daisy chain resistance change over time, a failure could be captured during cycling and eventually the failure data could be used to establish the solder joints failure distribution under different testing conditions. One of the most debatable matters is that when should one to determine a failure to occur. Per IPC 9701A [1] a failure is defined as 10 1000-ohm events in 1 micro-second duration for event detector or 20% increase over the baseline resistance for data logger. Other threshold values such as 100, 300, or 500 ohms are also commonly used by packaging reliability community. Such a wide range of failure threshold values may introduce significant delta in terms of cycle numbers for Pb-free solder joints if different criteria would be used as reported by Henshall, etc [2]. Therefore a systematic study of the impact of using such diversified resistance values on the final failure distribution is necessary and important such that no big difference among reliability results from different sources.

The purpose of this study is to investigate the impact of different failure thresholds on Pb-free solder joint failure distribution for most commonly used packages. The test vehicle, designed on an 8”x15” double-sided printed circuit board (PCB) with multiple test sites, was populated on both sides with daisy-chained components. To reflect the real situation, the components were selected to include different package types (FCBGA, PBGA, CSP, QFN, etc), different pitches (0.4-1.0 mm), and different package size (6-50mm). The assembled test vehicles then went through 0C-100C thermal cycling, the cycle numbers corresponding to different resistance thresholds were recorded and compared. The test results showed that the failure threshold has significant impact on Pb-free solder joint failure distribution, thus it is important to unify the failure criterion such that the reliability results from different sources could be compared side by side. For some packages especially small wire-bond packages that have relatively low baseline resistance, the 20% failure criterion may be too sensitive to the resistivity changes caused not by solder joint failure but other events such as connection cable resistivity change over time or temperature.

INTRODUCTION

When performing board level qualification tests, the failure criterion is one of the key area need to be addressed. In practice, daisy-chained components are often used so that the circuit chains through the critical solder joints could be monitored real time in the duration of qualification testing. A typical failure is defined, per industry specifications such as IPC 9701A [1], as the resistance of the chain reaches certain threshold number. The initial resistance which includes the chain resistance inside the component and the wire connected the component to the monitoring equipment varies significantly from package type and daisy chain design.

Table 1. component list

Package	I/O	Package size, mm	Die size, mm	Pitch, mm	Supplier
uCSP98	98	7.15x6.7	7.15x6.7	0.5	Amkor
tsCSP200	200	10x10	4.5x4.5	0.5	Amkor
PBGA680	680	35x35	17.5x17.5	1	Amkor
MLF68	68	10x10	4.5x4.5	0.5	Amkor
CTBGA208	208	17x17	11.43x11.43	0.8	Amkor
CBGA400	400	27x27	n/a	1.27	TopLine
LGA133	133	15x15	9.57x14.82	1.27	Linear
CVBGA432	432	13x13	7.15x6.7	0.4	Amkor

TEST VEHICLE DESCRIPTION AND TEST CONDITIONS

Component: A variety of components were selected to represent the typical surface mount BGA packages. These daisy-chain components as shown in Figure 1 covered a wide range of pitches, package size, die size, and ball maps. Listed in Table 1 are the common parameters of the packages used in this study.

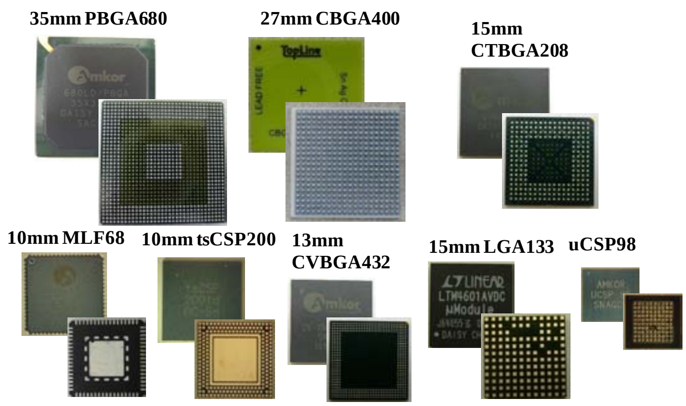


Figure 1. daisy-chain components used in this study

Test board: multiple test sites were designed onto an 8”x15” 93mil-thick double-sided printed circuit board (PCB) to accommodate different type of components. The PCB material is high Tg FR4. The PCB pad finish is OSP. Figure 2 and Figure 3 showed respectively the top and bottom view of an assembled test board.

SMT Assembly: Solder bridging is one of the most common challenges for fine pitch BGA assembly. To achieve good assembly yield of the test vehicle, a 3.5mil-stencil was used, the typical reflow profile is showed in Figure 4. Very good yield has been achieved with an optimized SMT process. Figure 5 shows a representative post assembly X-ray image of the assembled parts.

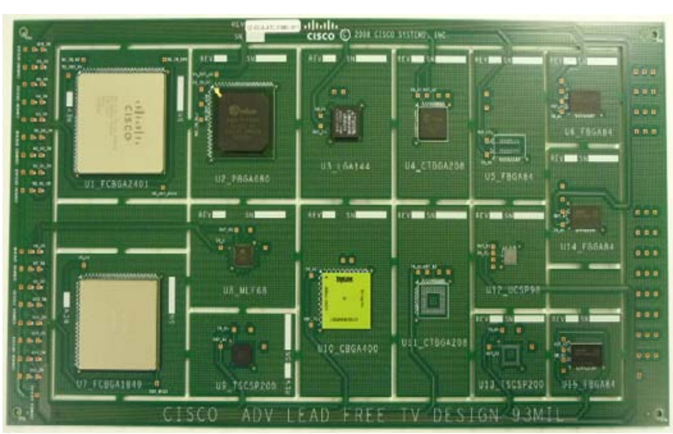


Figure 2. Top view of an assembled test vehicle

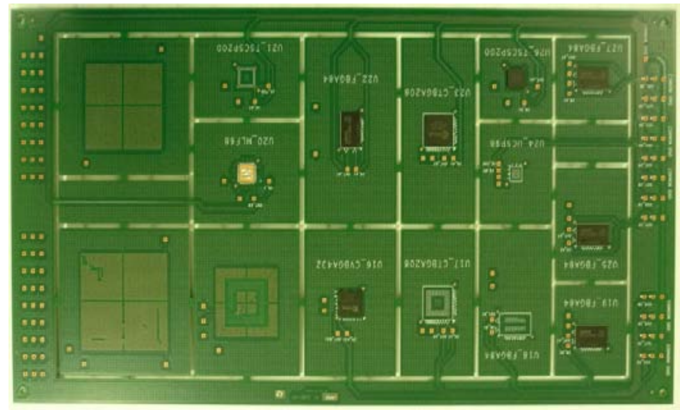


Figure 3. Bottom view of an assembled test vehicle

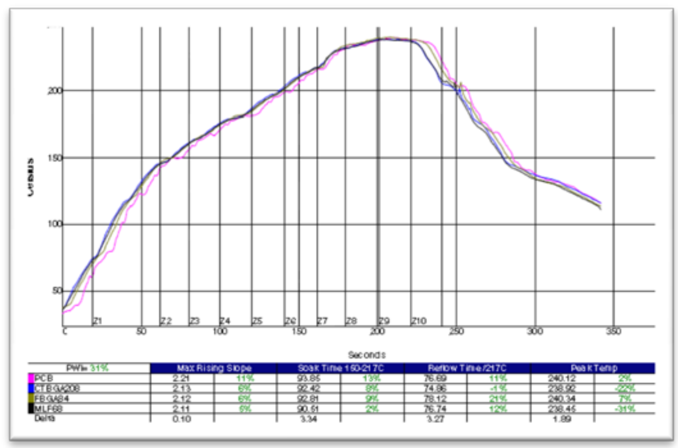


Figure 4. Typical reflow profile

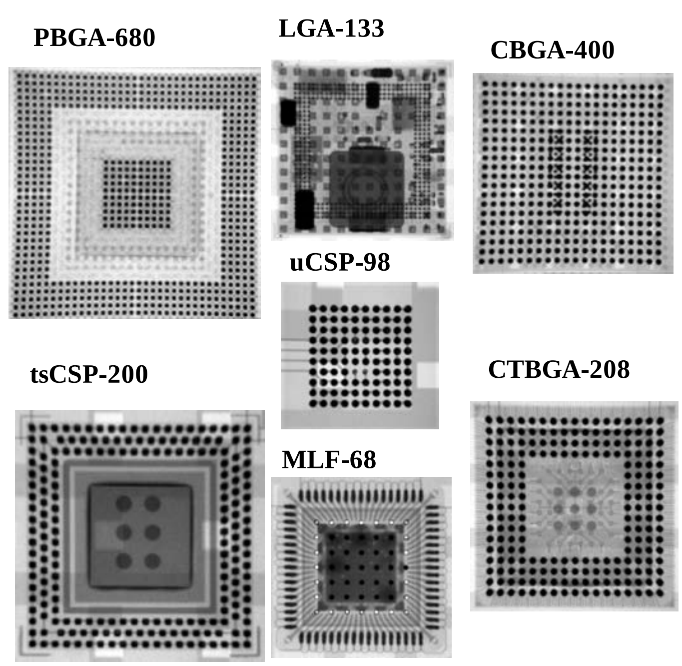


Figure 5. representative X-ray images of components post assembly

Test conditions and set up: Two temperature profiles (as shown in Figure 6) have been used in this study. Profile 1 was the standard 0/100̊C 40min/cycle (10 minutes ramp up and down, 10 minutes hot and cold dwell) as specified in IPC 9701A [1]. Profile 2 was modified based on the 1st 0/100˚C profile to take account of the mini cycle effect. The modified profile has 10 mini cycles at the hot dwell, i.e. 100̊C. Each mi ni cycle has a 10˚C temperature swing and 5˚C/min ramp rate. To study the isothermal aging impact, one leg of samples were thermally aged under 100˚C for 1000 hours before cycled under standard profile 1.

The continuity of all components was monitored with datalogger through 2-wire configuration for maximize the channel availability. Table 2 showed the resistance reading post assembly, post 1000-hour isothermal aging and post wiring scanned at 100̊C. Isothermal aging showed no significant impact on the daisy chain resistance. The post wiring resistance also includes the resistance of the wires and connectors link the component to the monitoring equipment due to the 2-wire configuration used. The initial resistance was below 10 ohms except for uCSP98. From Table 2, it is obvious that the connection resistance (the wires, the connectors etc) was comparable or larger than the original component daisy-chain resistance. One issue encountered in the testing was that the resistance increase was largely due to the increase of the connection resistance instead of joint cracking. To minimize the impact of connection resistance, the 4-wire configuration is recommended if 20% resistance increase were to be selected as the failure threshold.

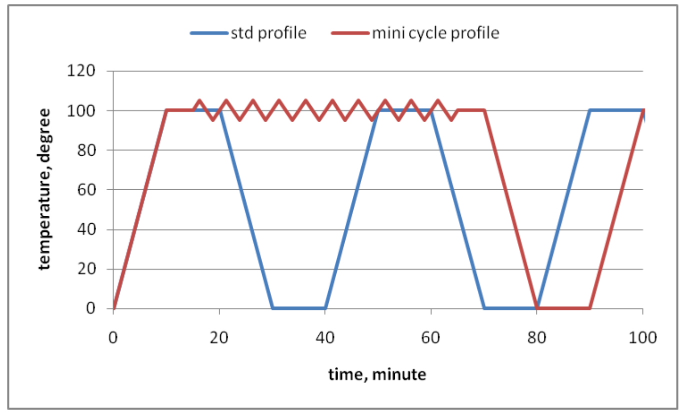


Figure 6. nominal accelerated thermal cycling (ATC) profiles

TEST RESULTS AND DISCUSSION

The cycles corresponding to 20% resistance and hard open were recorded. The hard open was defined as when the chain resistance beyond 1000 ohms for chains with a initial resistance less than 100 ohms or beyond 5000 ohms if the chain initial resistance greater than 100 ohms. Figure 7 showed the typical failure distributions of a component corresponding to 20% resistance increase and hard open. Table 3 summarized all ATC results under different conditions. Failure analysis confirmed no anamority in terms of joint microstructure and IMC formation. Representatively, Figure 8 and Figure 9 showed a good and a cracked joint respectively. The predominated failure mode was found to be the crack penetrating through the joints near the IMC at the component side as shown in Figure 10.

Table 2. daisy-chain resistance reading (unit: ohm)

package	net	post assembly		post aging		post wiring @ 100C	
		mean	std dev	mean	std dev	mean	std dev
PBGA-680	1	2.84	0.30	2.27	0.18	8.46	1.40
	2	1.89	0.23	1.65	0.14	7.19	1.54
LGA-133	1	1.86	0.29	1.76	0.18	8.33	1.21
CTBGA-208	1	1.56	0.26	1.77	0.22	5.40	1.48
MLF-68	1	1.98	0.10	1.77	0.06	7.32	1.52
tsCSP-200	1	4.84	0.19	4.72	0.51	9.62	1.48
CBGA-400	1	3.74	0.31	3.31	0.26	9.48	1.41
uCSP-98	1	58.07	3.11	59.72	2.49	69.22	1.59
CVBGA-432	1	1.74	0.28	1.67	0.61	7.08	1.43

Table 3. Weibull characteristic life corresponding to 20% resistance increase and hard open

package	Pkg size, mm	die size, mm	pitch, mm	std ATC			w/ mini cycles			aged then std ATC		
				20% inc	hard open	delta, %	20% inc	hard open	delta, %	20% inc	hard open	delta, %
uCSP98	7.15x6.7	7.15x6.7	0.5	1638	1662	1.5%	1162	1443	24.2%	1838	2237	21.7%
tsCSP200	10x10	4.5x4.5	0.5	2092	2098	0.3%	1696	1898	11.9%	1476	1872	26.8%
PBGA680	35x35	17.5x17.5	1	8461	8589	1.5%	4837	4894	1.2%	-	-	-
MLF68	10x10	4.5x4.5	0.5	7839	8227	4.9%	4790	4975	3.9%	-	-	-
CTBGA208	17x17	11.43x11.43	0.8	2804	2834	1.1%	2332	2472	6.0%	2901	3702	27.6%
CBGA400	27x27	27x27	1.27	980	1228	25.3%	790	1128	42.8%	1060	2019	90.5%
LGA133	15x15	die 1: 2.41x2.95 die 2 (top): 1.96x3.99 die 3 (bot): 2.54x3.99	1.27	8736	8917	2.1%	4580	4900	7.0%	-	-	-
CVBGA432	13x13	12.2x12.2	0.4	512	540	5.5%	413	441	6.8%	445	575	29.2%

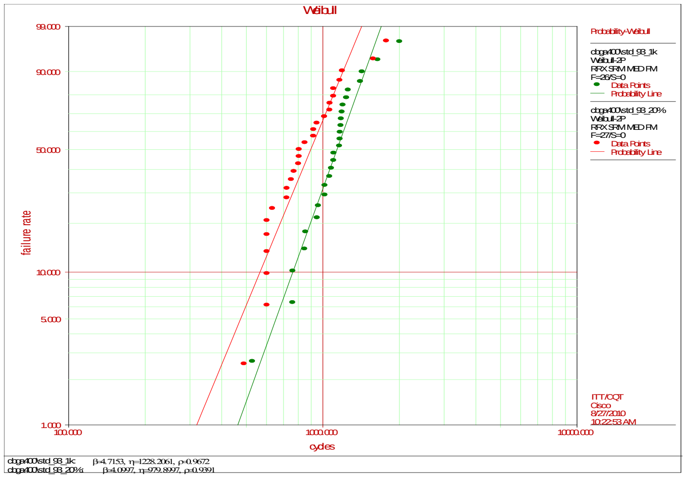


Figure 7. typical failure distribution corresponding to 20% resistance increase and hard open respectively

Under standard profile 1, the gaps between the characteristic lives using 20% resistance increase and hard open were generally less than 10% except for CBGA. Under modified profile with mini cycles at high temperature dwell, the gaps increased significantly. After isothermal aging, the deltas were over 20%.

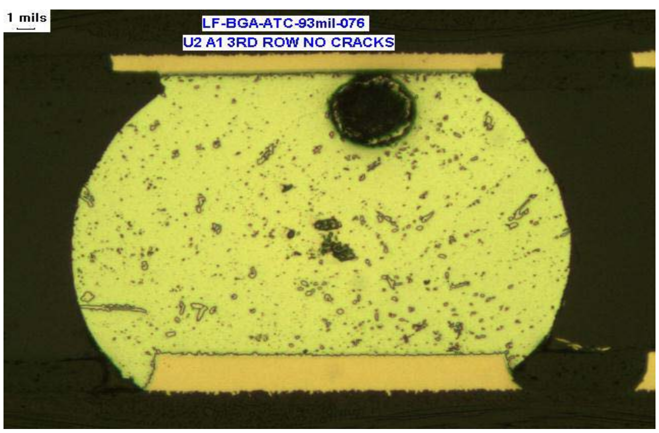


Figure 8. cross section view of a good joint

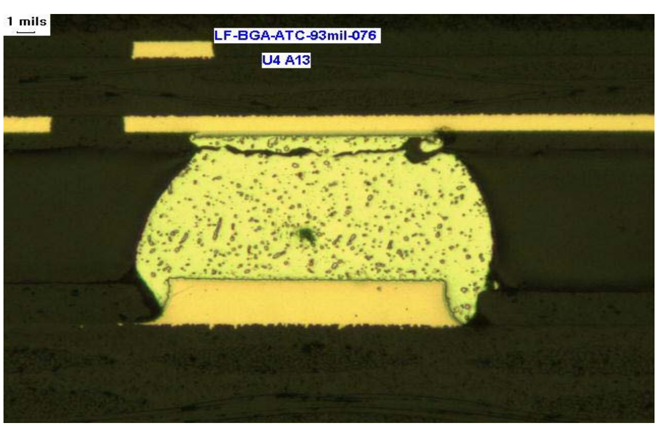
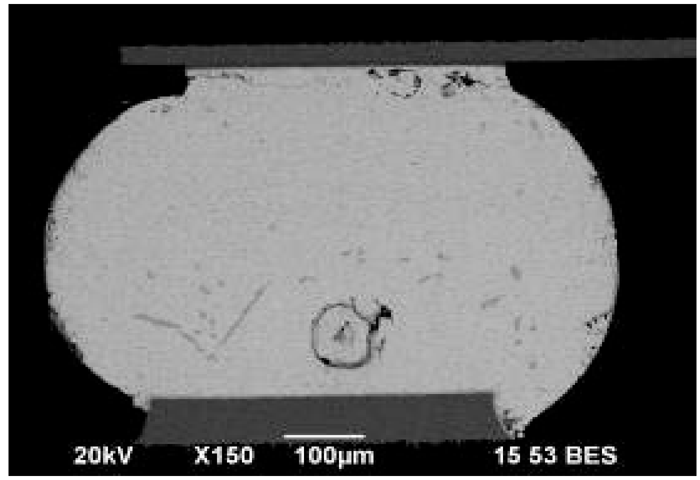
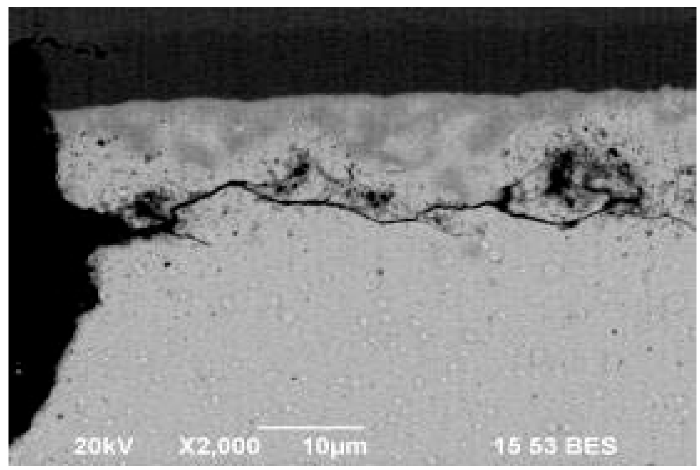


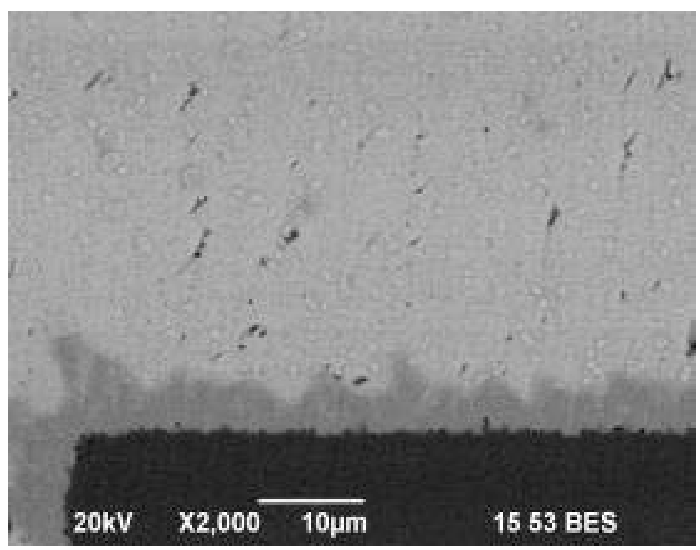
Figure 9. cross section view of a cracked joint



a) a cracked joint



b) zoom in view at component side



c) zoom in view of PCB pad side

Figure 10. SEM picture of a) a crack joint, b) zoom in picture to show crack near IMC on component side, and c) IMC formation near PCB pad

CONCLUSIONS

A systematic study on the failure criterion of Pb-free board level reliability testing was performed. The results of this study showed that under standard 0/100˚C condition, the differences in terms of Weibull characteristic life by using 20% resistance increase and 1000 ohms were less than 10% in general but significant changes may occur under different thermal cycling conditions. The 4-wire configuration should be used if 20% resistance increase were to be used as the failure criterion to eliminate the connection resistance.

ACKNOWLEDGEMENT

The authors want to acknowledge Hien Ly at Jabil Circuit, Inc of San Jose for his contribution in test vehicle assembly and constructive suggestions in test vehicle design. Special appreciation also goes to Laura Luo, and Raul Armendariz of Cisco HALT lab for facilitating part of thermal cycling.

REFERENCE

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2. Henshall, G., “Comparison of thermal fatigue performance of SAC105, Sn-3.5Ag, and SAC305 BGA components with SAC305 solder paste,” APEX’09, 2009.