LF-C2 Alloy for Harsh Environment Assembly

Background

In recent years there has been a demand for solder alloys with better resistance to thermal fatigue. LF-C2 has been developed as a response to that demand.

Increasing the hardness of a solder alloy does not necessarily mean that its resistance to thermal fatigue will increase. High hardness, i.e. resistance to deformation, means that the full applied load will be transmitted to the interfaces. LF-C2, with a good balance of hardness and compliance delivers superior resistance to thermal fatigue. And this alloy has the additional benefit of a low incidence of voiding.

The microstructure of an LF-C2 solder joint addresses thermal fatigue challenges facing products designed for high temperature, high vibration environments. The creep resistance and tensile strength of the LF-C2 alloy enhances reliability beyond the capabilities of standard SAC alloys.

Physical Properties

Items	LF-C2	SAC305	Test Method
Solidus(^oC)	205	218	Differential scanning calorimetry: Temperature ramp rate:2^oC/min、Measurement range 30-300^oC JISZ3198-1
Liquidus(^oC)	213	219	
Specific gravity (g/cm^3)	7.5	7.4	Archimedes method, Weight of water displaced
Tensile strength (MPa)	90	48	Strain rate 10mm/min、Test temperature:25^oC
Elongation (%)	16	33	Strain rate:10mm/min, Test temperature:25^oC
0.2%Proof stress (MPa)	61	41	Strain rate:10mm/min、Test temperature:25^oC
Young's modulus (GPa)	55	51	Free resonance method
Linear expansion coefficient (ppm/K)	24	23	Differential expansion method

Key Attributes

- LF-C2 alloy is designed to run in harsh environments with thermo-cycling & thermo-shock ranges of -40 °C to 150 °C
- Improved thermal management due to inherent creep resistance properties
- Reflow at temperatures lower than SAC305
- Improved performance in harsh environment applications such as under-hood automotive, advanced safety devices (ADAS), high power LED, and avionics/aerospace

The LF-C2 alloy is available in the following FCTA® Products:

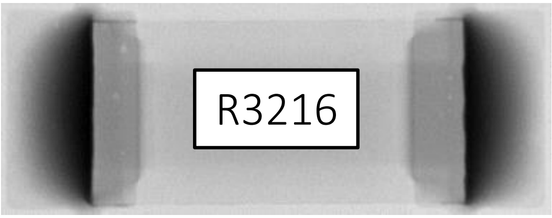
- AMP OnePT, AMP One, AMP Wash

High Thermal Fatigue Life Pb-free Solder:LF-C2

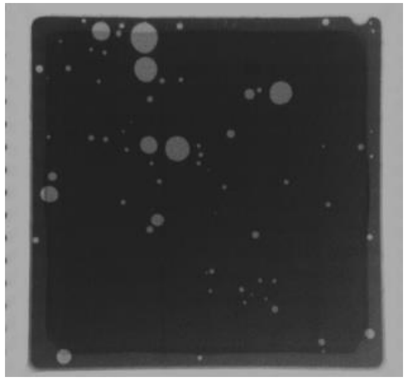
LF-C2 composition: Sn3.5Ag1.0Cu+3.0Bi

- <u>High Reliability</u>
  Slow crack propagation during thermal cycling
- <u>Low Voiding</u>
  Compared to other high strength alloys, with consequent improvement in reliability.
- <u>Low Melting Point</u>
  10^{o}C lower than SAC305

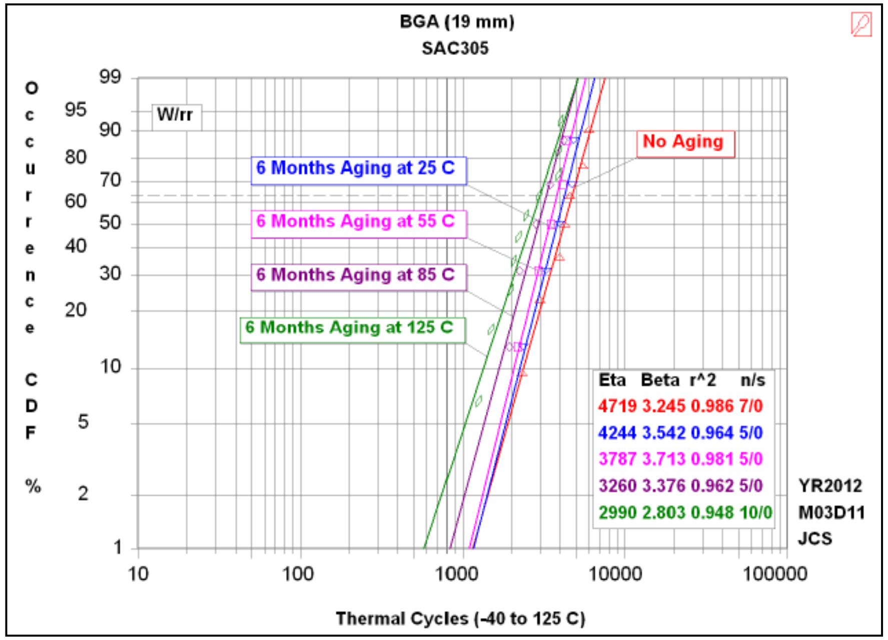
<u>X-ray image after soldering</u>

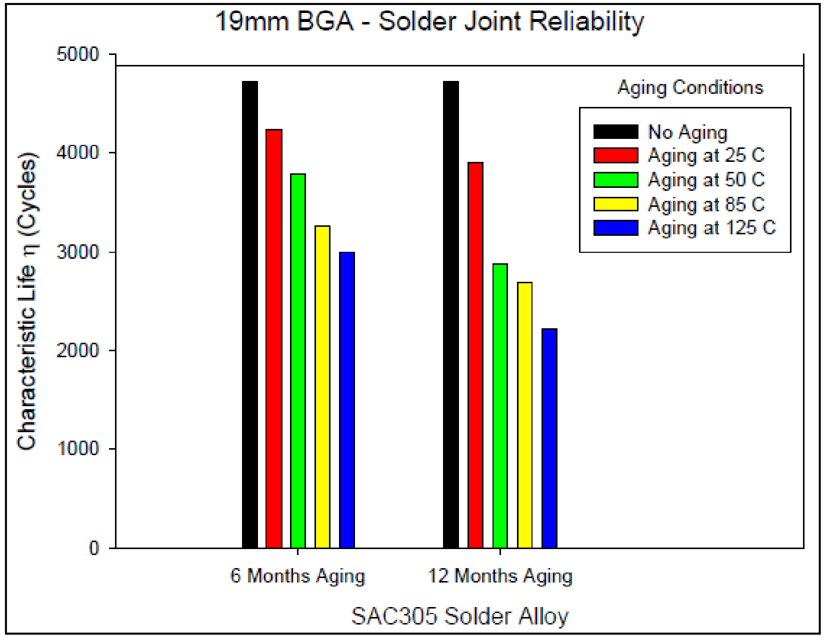


QFN(10mm)
Thermal pad



Limits of the Ag Strengthening Effect



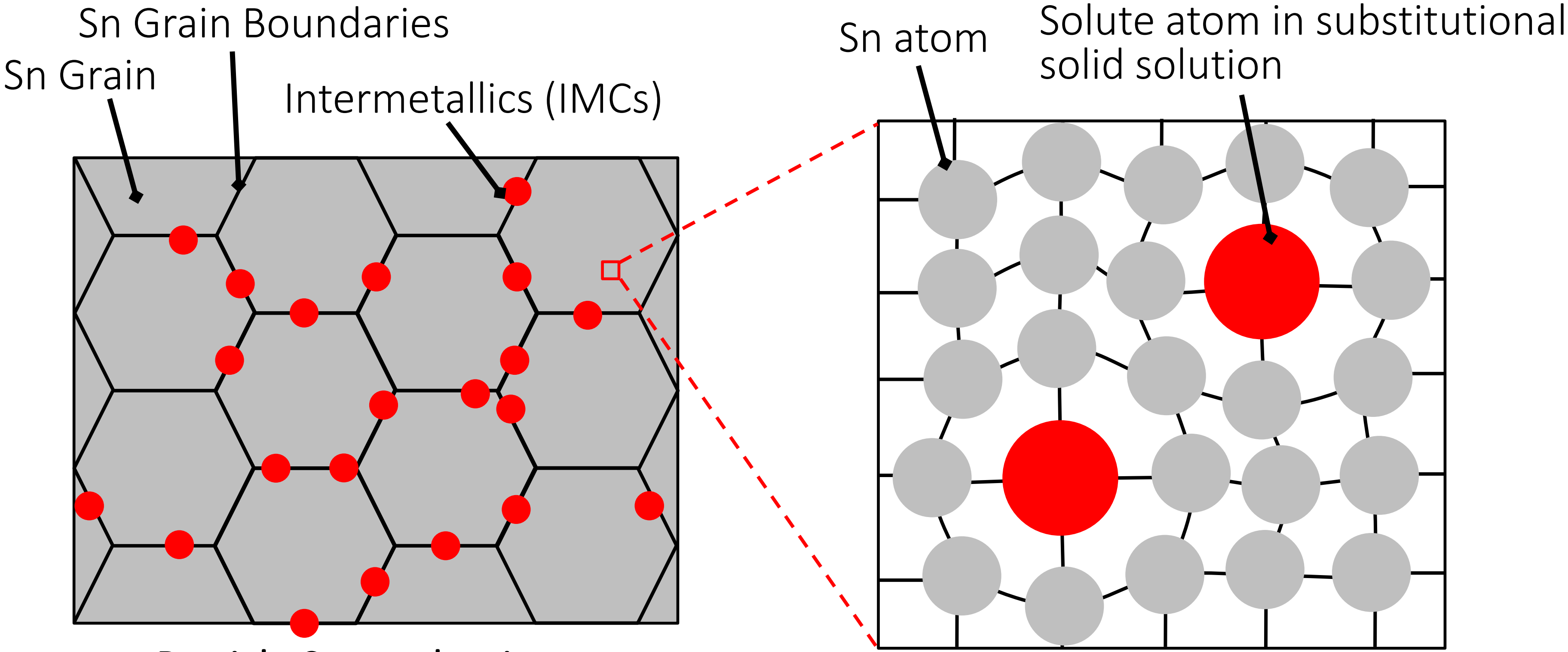


Motalab, M, *et. al.*, (2014), 'Correlation of Reliability Models Including Aging Effects with Thermal Cycling Reliability Data', SMTAI2014 Proceedings.

Thermal fatigue life of SAC305 joints declines with increasing ageing time and ageing temperature

- The effectiveness of the fine dispersion of Ag_3Sn as obstacles to dislocation movement declines as the particles coarsen and the interparticle spacing increases as result of Oswald ripening during isothermal ageing.
- As a consequence, the creep rate, a key determinant of joint life, accelerates.

LF-C2 Strengthening Mechanism



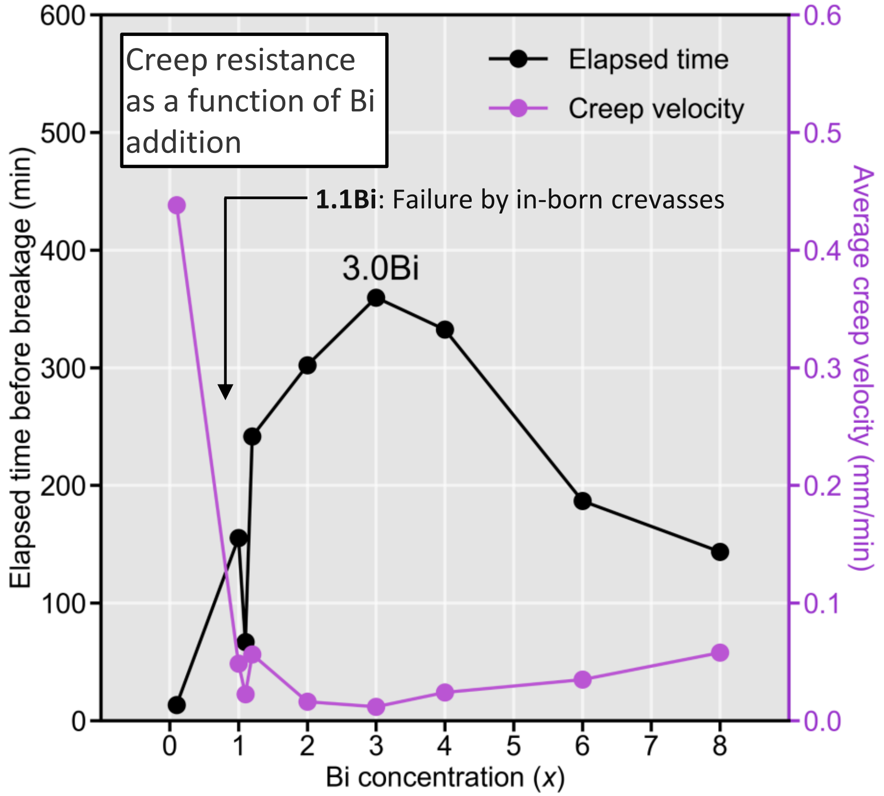
Particle Strengthening

Solid Solution Strengthening

- Both Particle Strengthening and Solid Solution Strengthening inhibit dislocation movement
- The characteristic thermal stability of LF-C2 is due to the combination of particle strengthening and solid solution strengthening effect.

Reason of 3% Bi Addition in LF-C2

Time/velocity vs. Bi



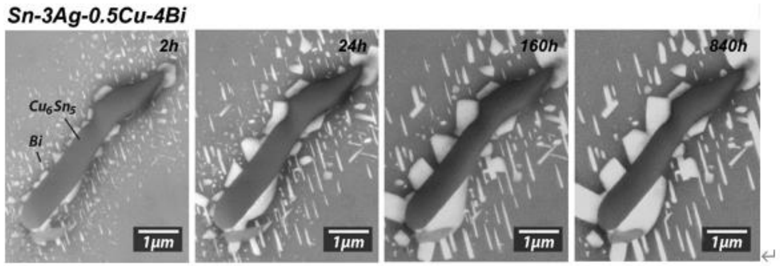
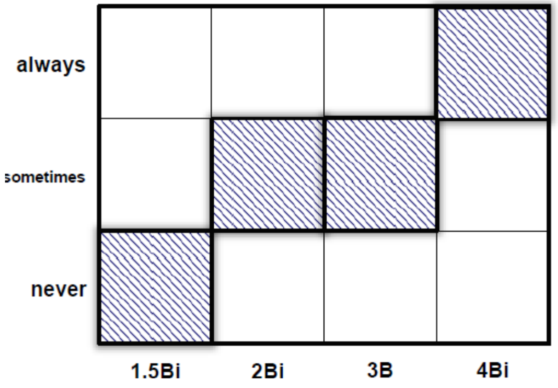


Figure 4. Precipitation and coarsening of (Bi) plates in Sn-3Ag-0.5Cu-4Bi and Sn-0.7Cu-0.05Ni-4Bi during storage at room temperature. Note that, for each alloy, the same area is shown at each time.

grain boundary (Bi) eutectic.

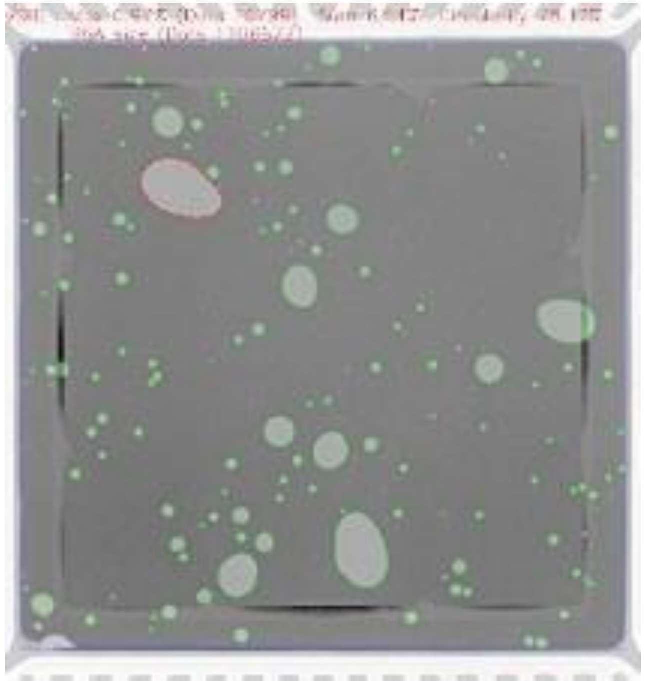
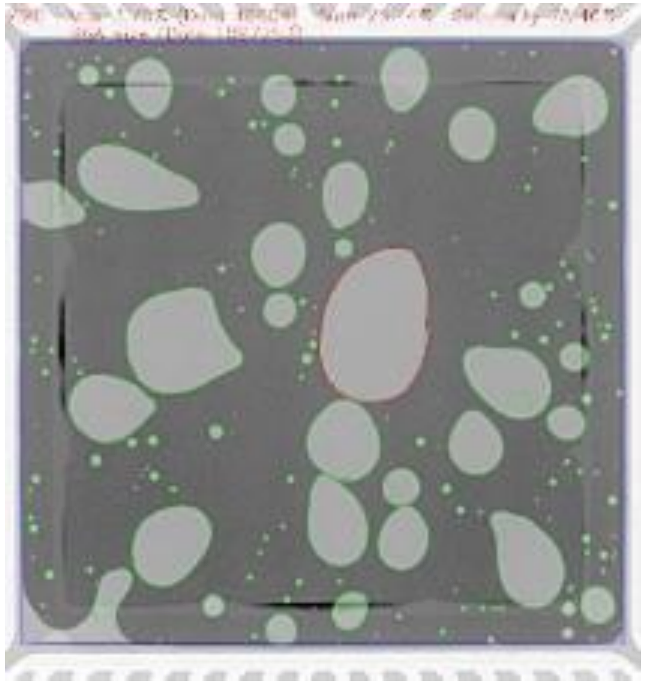


S. Belyakov, (2016) ,' Effects of Bi on microstructure formation of Sn-Cu-Ni-Bi based soldersSergey', Proceedings of TMS2016

Alloy with more than 3% Bi always shows brittle Bi phase.

- Solder with 3% Bi shows the best creep resistance. The alloy above 3% Bi content shows less effective in creep resistance because brittle Bi phase starts to be observed.
- LF-C2 (Sn3.5Ag1.0Cu3Bi) is designed SAC eutectic alloy (which contains slightly higher Cu to minimize Cu pad erosion) with 3% Bi as the optimum level Bi content.

Reason for No Sb in LF-C2

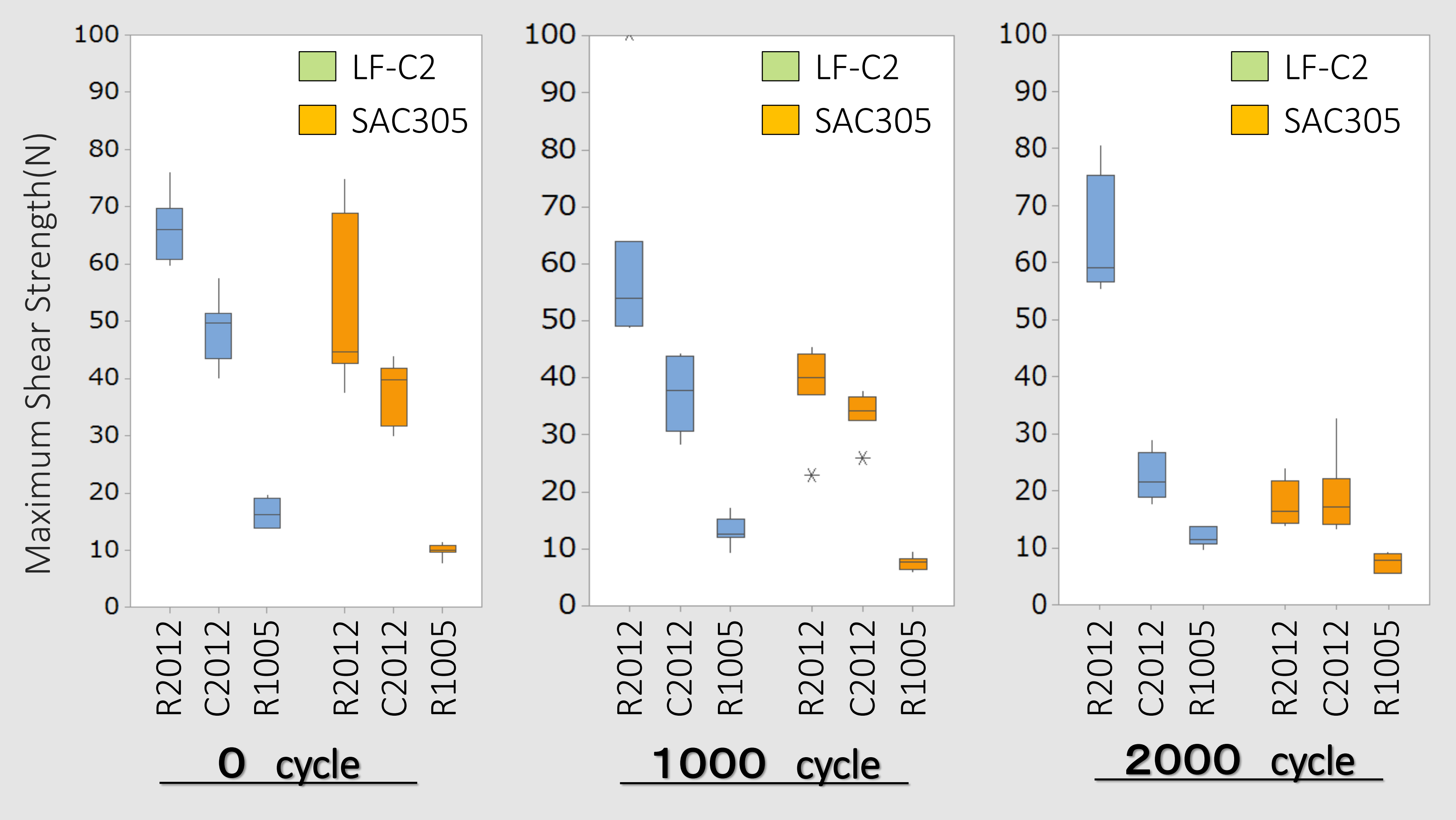
LF-C2	LF-C2+2Sb
	
6.5%	25.1%

- Addition of Sb makes the alloy more difficult property to outgas during reflow.
- LF-C2 is designed for wider component & process choices with better thermal fatigue than SAC305.

Shear Test Conditions

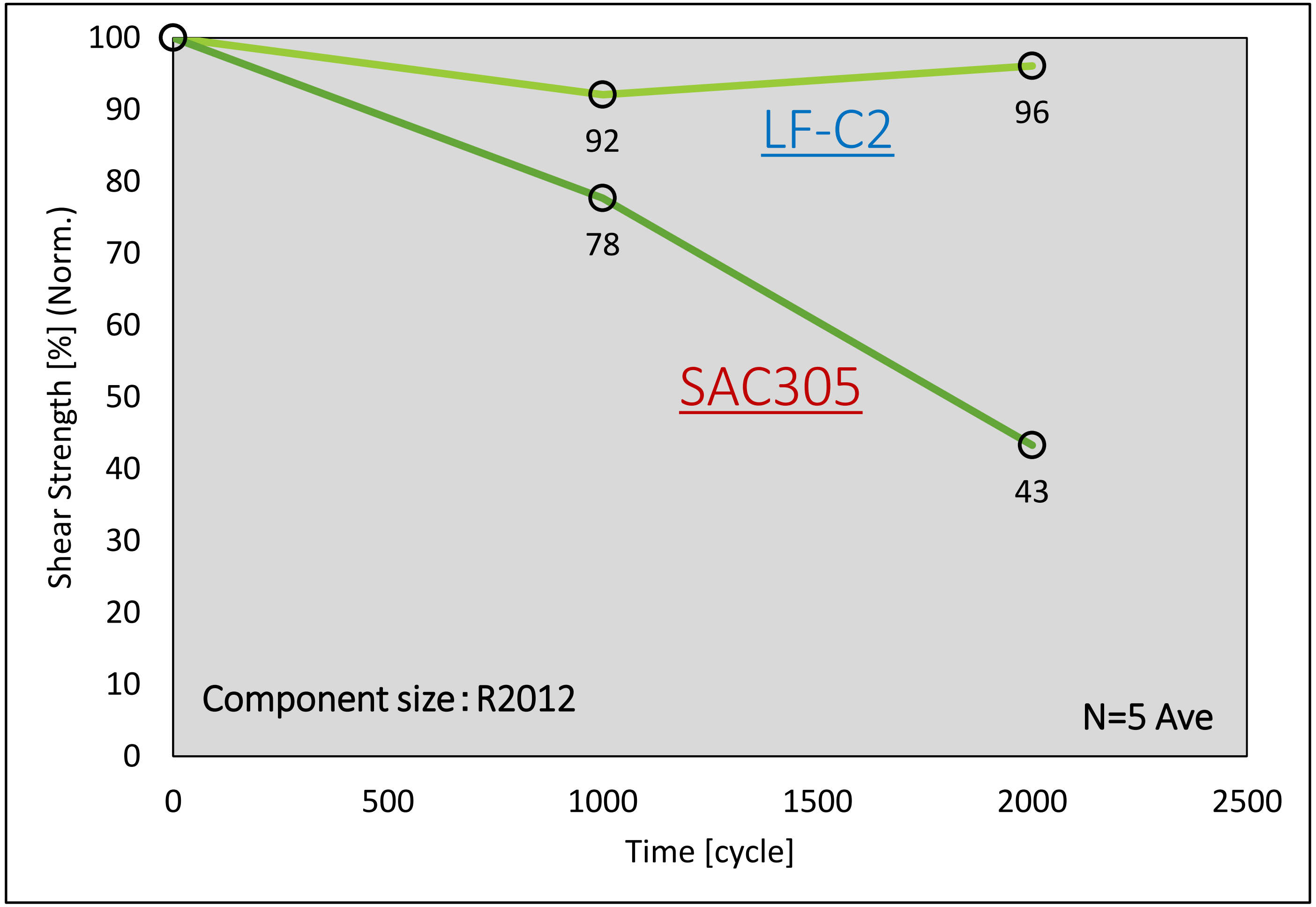
- Substrate
  - FR-4(Cu-OSP)
- Reflow conditions
  - Ramp-to-Peak profile
  - Ramp Rate: 1.5℃/sec, Peak temperature: 245℃ 60sec
- Thermal Shock conditions
  - -40℃/+125℃ Dwell Time: 30min
- Chip Shear conditions
  - Equipment: Autograph（Shimadzu）
  - Shear speed: 0.5mm/min
  - Component
    - Chip resistor (R1005, R2012 in metric size)
    - Chip capacitor (C1005, C2012 in metric size)
  - Sample number: 5

Shear Test Results



LF-C2 shows smaller shear strength degradation than SAC305.

Shear Test Results

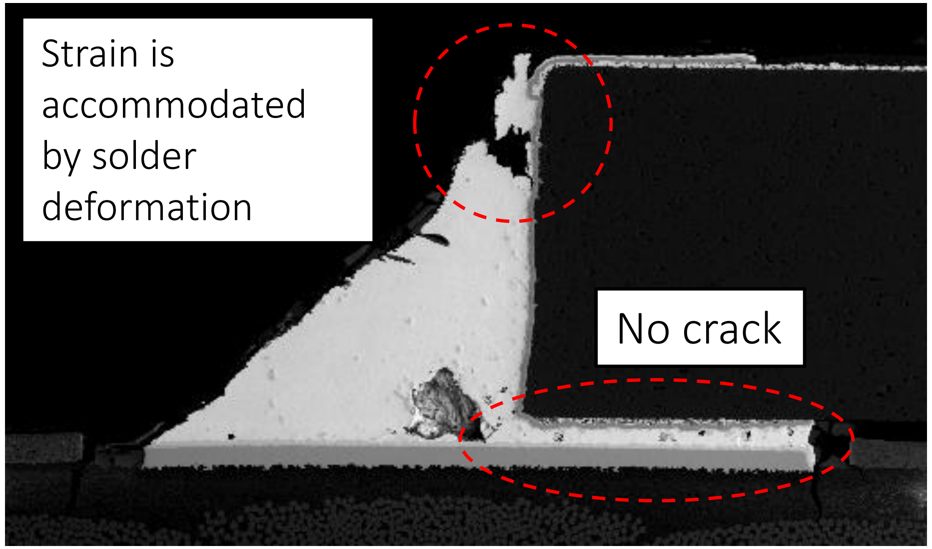


LF-C2 shows smaller shear strength degradation than SAC305.

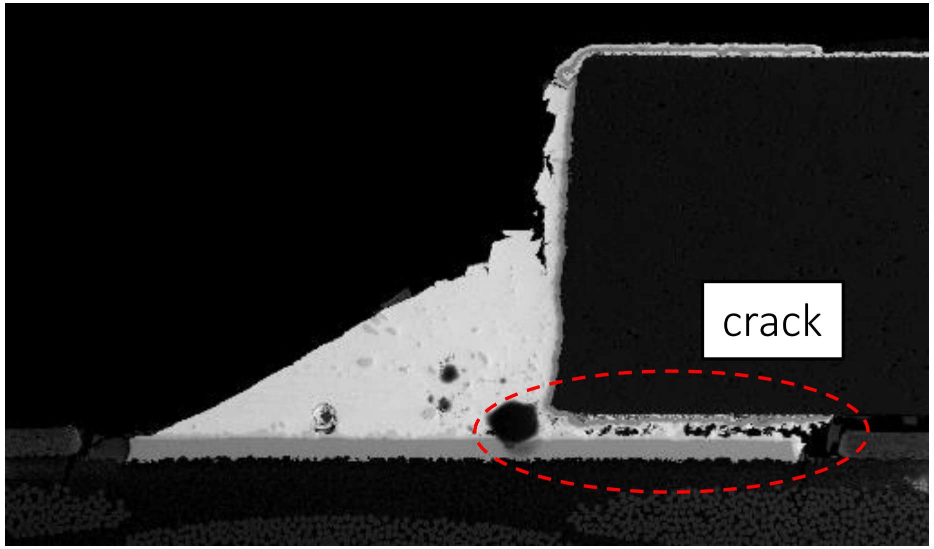
Cross-Section Analysis LF-C2 vs SAC305

Component Type: R2012

LF-C2



SAC305

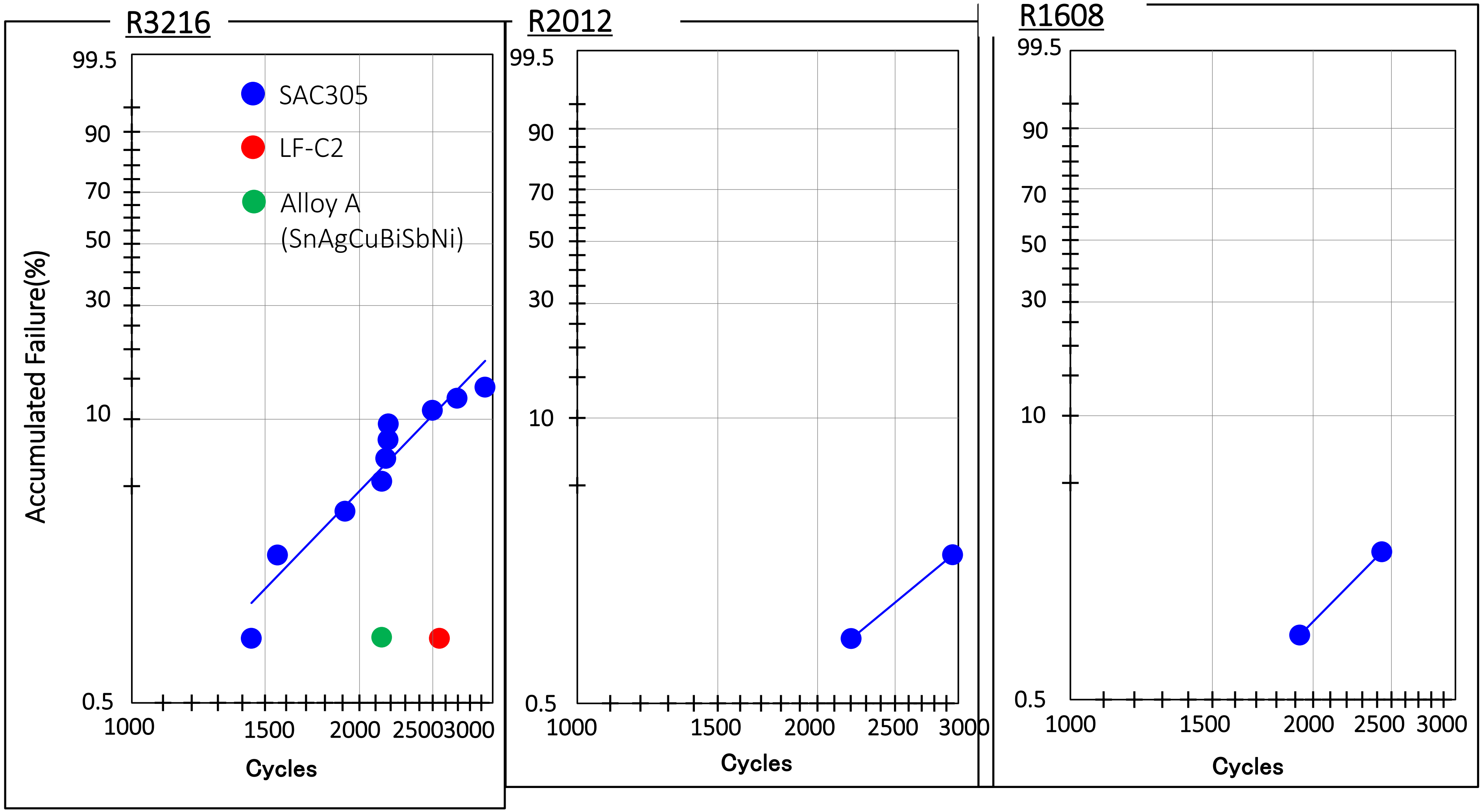


No crack is observed in the LF-C2 underneath the component, and by accommodating strain LF-C2 also minimizes damage to components and PCB

Thermal Shock Test Condition

- Substrate
  - FR-5(Cu-OSP)
- **Alloy**
  - SAC305
  - Alloy A (SnAgCuBiSbNi)
  - LF-C2
- Reflow condition
  - Ramp-to-Peak
  - Ramp rate: 1.5℃/sec, Peak temperature: 245℃ 60sec
- Thermal shock condition
  - -40℃/+150℃ Dwell time 30min
- Component size
  - R3216 in metric (Sample number: 70)

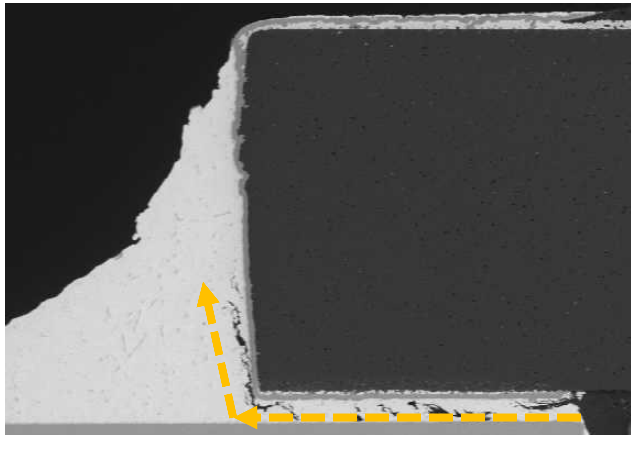
Thermal Shock Test Condition



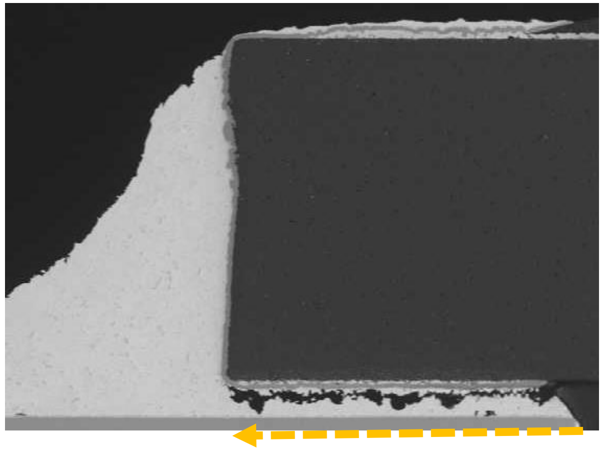
LF-C2 showed significantly higher life than SAC305 and Alloy A (SnAgCuBiSbNi).

Cross-Sectional Analysis LF-C2 vs SAC305 (after 1000 cycles)

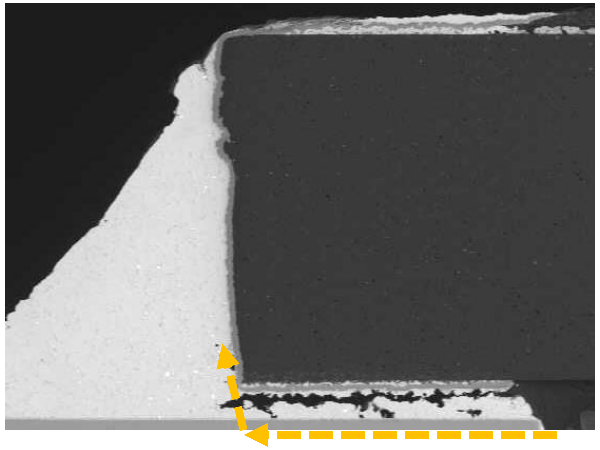
SAC305



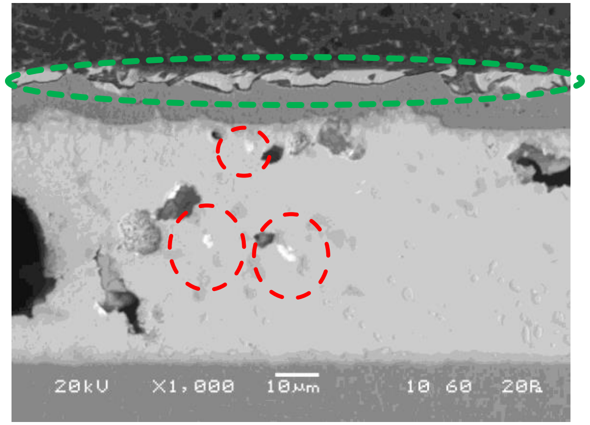
LF-C2



Alloy A



Only in Alloy A



Yellow Line: Solder Crack
Red Circle: Brittle Bi phase
Green Circle: Terminal Delamination

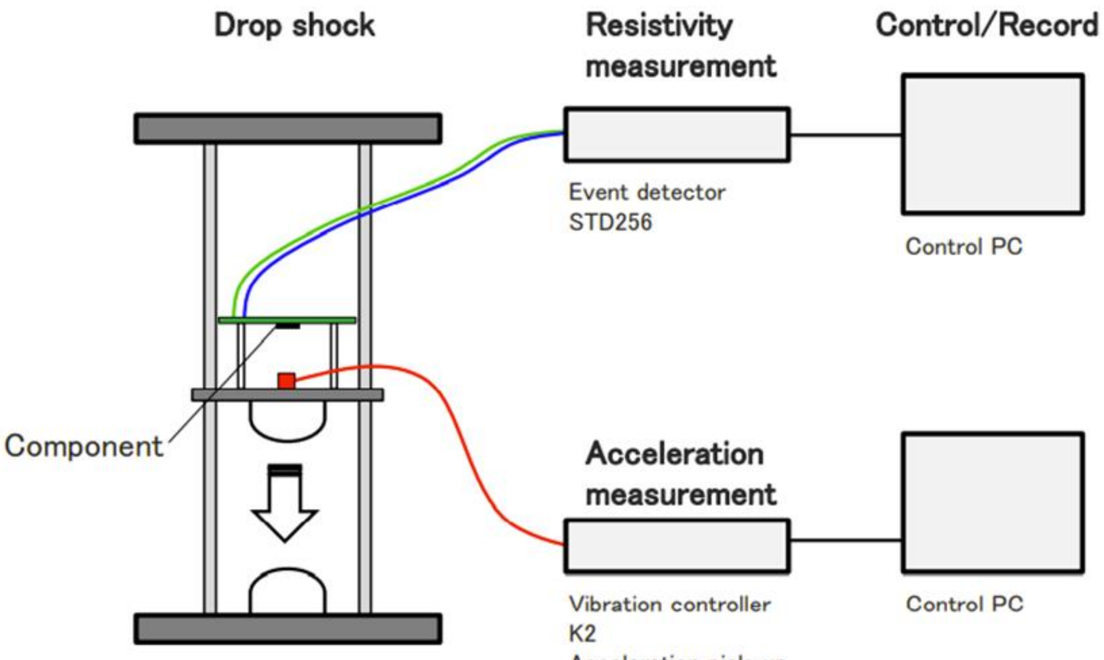
- All Solder showed solder crack and the crack length was: SAC305 < Alloy A ≅ LF-C2
- Only in Alloy A, component terminal delamination was observed.
- This is because the Alloy A is the hardest in three choices and the terminal metallization failed by the strain during thermal cycling test.

Drop Shock Test

■Apparatus

Drop shock test apparatus

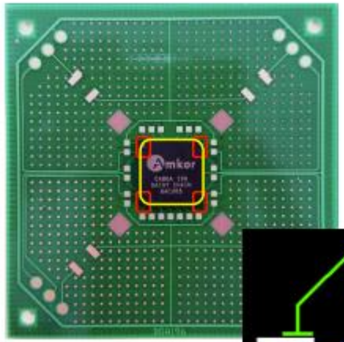
Image of apparatus



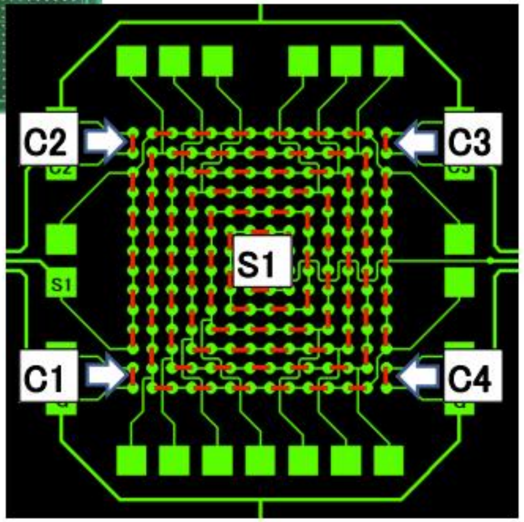
Drop shock test apparatus
FIT-1500G

Drop Shock Test (Conditions)

Test PCB appearance



Circuit pattern



Disconnection detection point	Corner	4 points :C1,C2,C3,C4
	Whole part	1 point :S1

【Materials information】

Item	Name	Note
Solder paste	SN97C P608 D4 (SAC305)	Sn-3Ag-0.5Cu
	SN100CV P608 D4	Sn-1.5Bi-0.7Cu-Ni-Ge
	LF-C2 P608 D4	Sn-3.5Ag-3Bi-1Cu
Component	CABGA196 (A-CABGA196-1.0-15mm-DC-LF-305)	15x15mm, 1.0mm pitch Solder ball alloy : SAC305
Substrate	NS drop test board (JEDEC JESD22-B111A)	76x76x1mm FR-4, Cu-OSP, 6 layers, non-through hall

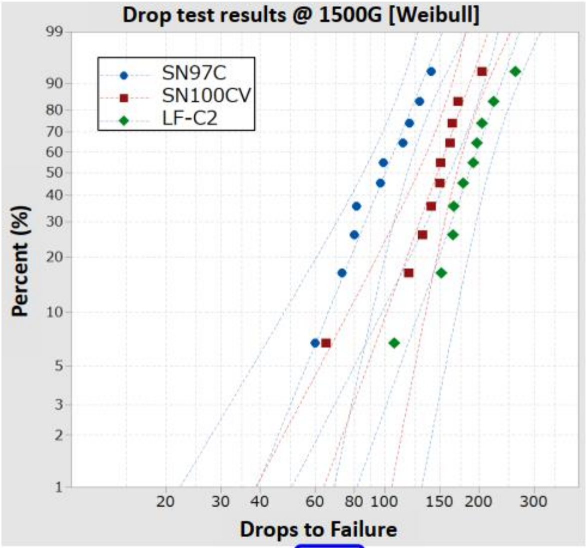
【Drop conditions】

Item	Conditions
Max. acceleration	1500 G (on the center of PCB)

【Stencil information】

Item		Conditions
Stencil	thickness	100 µm

Drop Test Results



	形状	尺度	N	AD	p値
SN97C	4.487	109.1	10	0.210	>0.250
SN100CV	5.058	158.8	10	0.322	>0.250
LF−C2	5.121	200.4	10	0.212	>0.250

Characteristic Life
(Number of drop when 63.2% of the total breaks)

⇒Characteristic life is longer in the order of
LF-C2 > SN100CV > SN97C

Drop Test Results ～1500G～

NIHON SUPERIOR

Table.1-1 Drops to Failure ※ascending order

[Unit : times]

Solder alloy	Numbers of Test										Ave.
	1	2	3	4	5	6	7	8	9	10	
SN97C	60	73	80	81	97	99	114	120	129	141	99.4
SN100CV	65	119	132	141	150	151	162	164	171	204	145.9
LF-C2	107	152	165	166	178	192	197	204	223	261	184.5

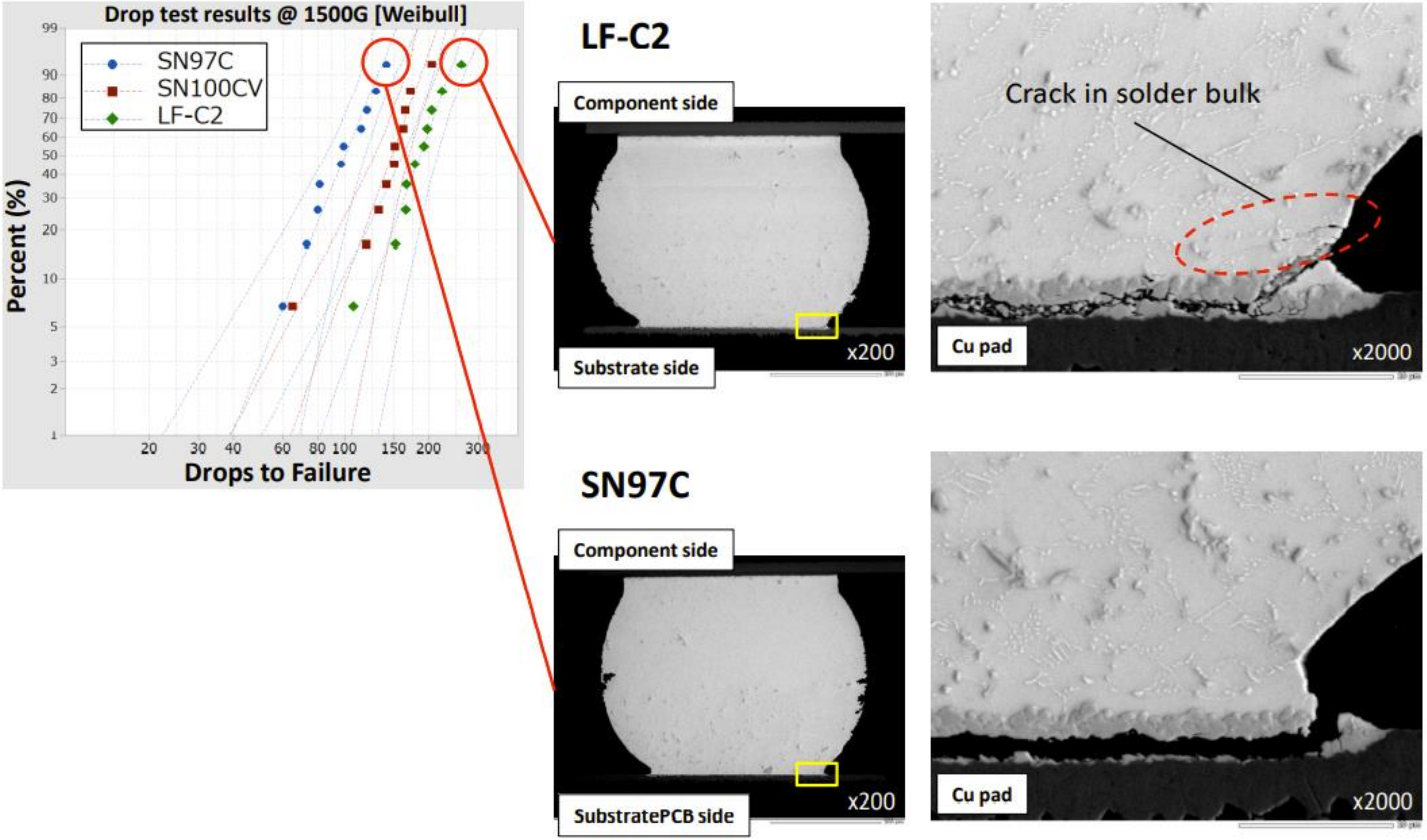
⇒ LF-C2 and SN100CV tend to be more impact resistant than SN97C

Table.1-2 Disconnection detection point

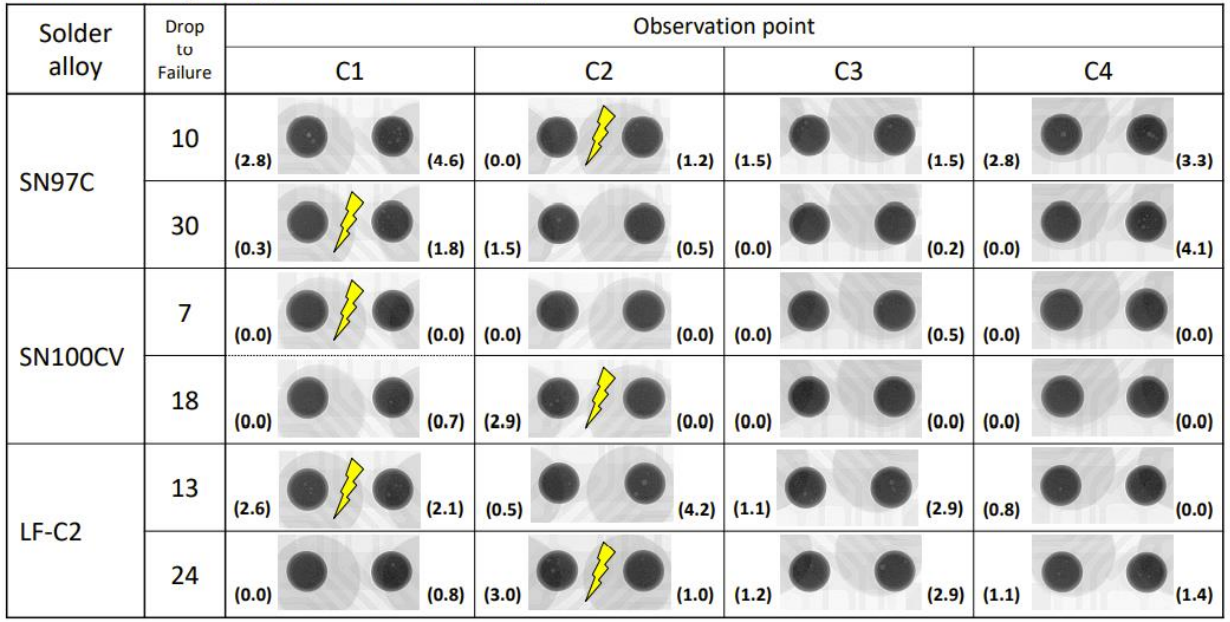
Solder alloy	Number of Test									
	1	2	3	4	5	6	7	8	9	10
SN97C	C1	C3	C2	C4	C2	C2	C4	C1	C2	C4
SN100CV	C2	C3	C3	C2	C2	C3	C4	C2	C2	C2
LF-C2	C4	C2	C3	C2	C3	C2	C1	C4	C2	C1

⇒For all solder alloys, the disconnection detection point is the corner

Drop Test Analysis (X-section observation 1500G)



Drop Test Analysis (X-ray observation 1500G)



※About Max. & Min. number of drop to failure

⚡ : Disconnection detection point

( ) Numbers in parentheses : Void occupancy(%)

Table.3 X-ray image and void occupancy

Solder alloy	Drop to Failure	Observation point C1	C2	C3	C4
SN97C	10	(2.8) (4.6)	(0.0) ⚡ (1.2)	(1.5) (1.5)	(2.8) (3.3)
	30	(0.3) ⚡ (1.8)	(1.5) (0.5)	(0.0) (0.2)	(0.0) (4.1)
SN100CV	7	(0.0) ⚡ (0.0)	(0.0) (0.0)	(0.0) (0.5)	(0.0) (0.0)
	18	(0.0) (0.7)	(2.9) ⚡ (0.0)	(0.0) (0.0)	(0.0) (0.0)
LF-C2	13	(2.6) ⚡ (2.1)	(0.5) (4.2)	(1.1) (2.9)	(0.8) (0.0)
	24	(0.0) (0.8)	(3.0) ⚡ (1.0)	(1.2) (2.9)	(1.1) (1.4)

⇒ Void occupancy tends to the following.
SN97C > LF-C2 > SN100CV

- Drop test performance, Characteristic life For 1500 G, LF-C2 had the longest characteristic life (about twice as SN97C=SAC305), followed by SN100CV and SN97C.
- Void observation by X-ray, and the void occupancy of all alloys was less than 5%. SN97C showed the highest voids, followed by LF-C2 and SN100CV

Drop Test Results 1500G

Table.1-1 Drops to Failure ※ascending order [Unit : times]

Solder alloy	Numbers of Test										Ave.
	1	2	3	4	5	6	7	8	9	10	
SN97C	60	73	80	81	97	99	114	120	129	141	99.4
SN100CV	65	119	132	141	150	151	162	164	171	204	145.9
LF-C2	107	152	165	166	178	192	197	204	223	261	184.5

⇒ LF-C2 and SN100CV tend to be more impact resistant than SN97C

Table.1-2 Disconnection detection point

Solder alloy	Number of Test									
	1	2	3	4	5	6	7	8	9	10
SN97C	C1	C3	C2	C4	C2	C2	C4	C1	C2	C4
SN100CV	C2	C3	C3	C2	C2	C3	C4	C2	C2	C2
LF-C2	C4	C2	C3	C2	C3	C2	C1	C4	C2	C1

- Cracks occurred in the solder bulk of the LF-C2, indicating that there was a stress load on this part. For SN97C (SAC305) the cracks occurred at the intermetallic compound layer (IMC).
- This is because the solid solution strengthening by bismuth in LF-C2 increases the solder bulk strength near the bonding interface. The characteristic life of the LF-C2 substrate is longer than that of the SN97C substrate.

Vibration Test Results

Test Conditions

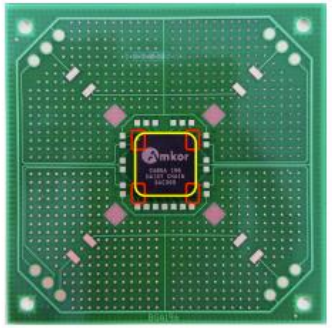
Test Vehicle

- Test Board : FR-4 (JEDEC Board_76x76x1mm, 6 layers, Cu-OSP, Non T/H)
- Component : BGA196 (SAC305, 460um)
- Stencil Thickness : 120um
- Solder Alloy : LF-C2, Alloy A, SAC305

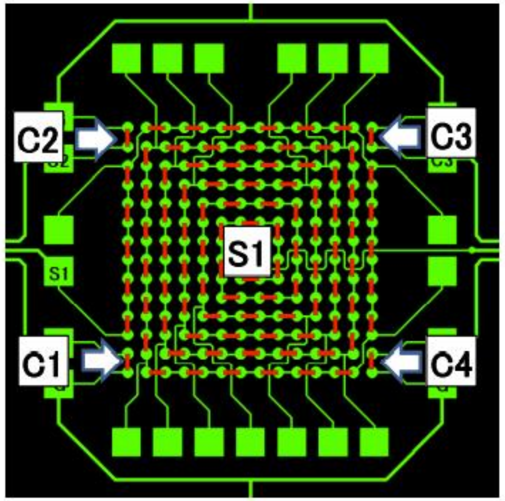
Vibration Condition

- Vibration Mode : 395Hz, Primary resonance
- Amplitude : 8G
- Equipment : m120-CE (IMV)

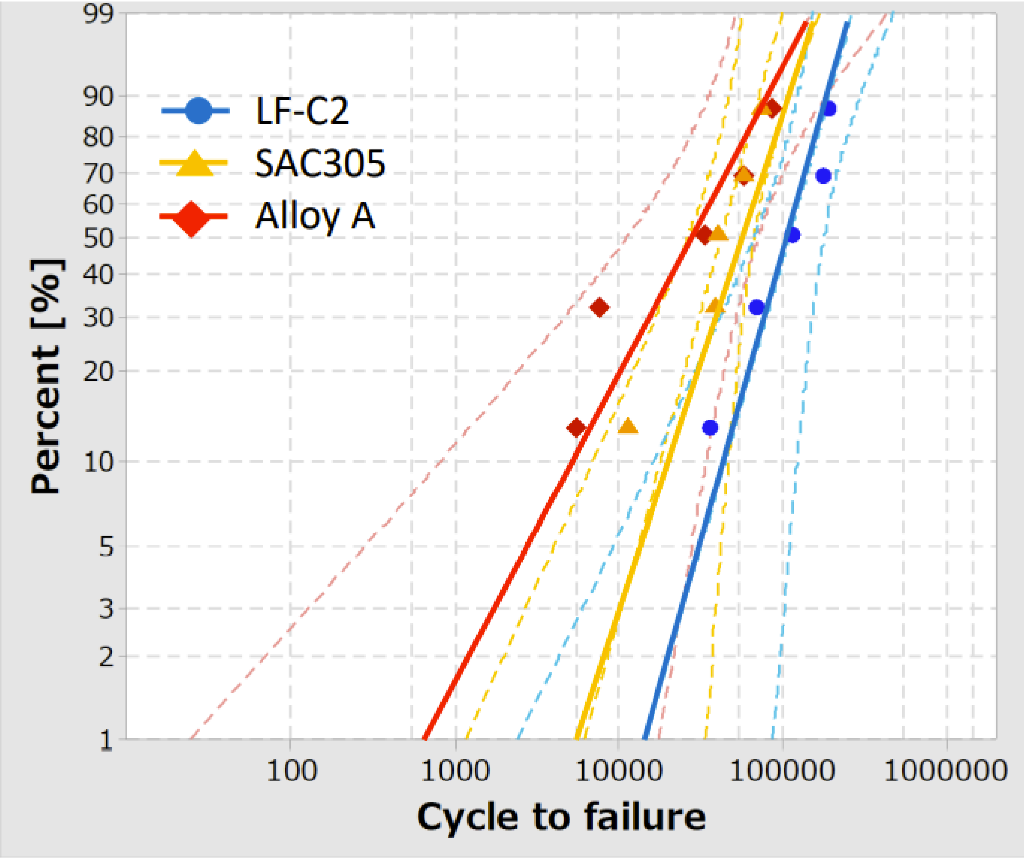
Appearance



Daisy Chain Design



Vibration Test Results



The vibration life is the longest with LF-C2 that is significantly longer with SAC305 and the shortest with Alloy A.

Voiding Rate & Wetting Performance
LF-C2 vs. Leading Competitor Alloy

Test Conditions

Component	Material	Note		
Solder Paste	LF-C2	Solidus : 208℃ Liquidus : 213℃		F%=11.2% 166Pa･s, TI=0.51
	Competitor Alloy	Solidus : 207℃ Liquidus : 220℃		F%=11.2% 172Pa･s, TI=0.58
Components	CR2125	Number : 27 L2.0 × W1.25 mm		
	LED	Number : 10 L2.4 × W1.85 mm		
	PBGA256	Number : 2 BGA Ball size(SAC305) : 500µm		
	MLF-68	Number : 6 10 × 10 mm		
	SOT23	Number : 15 L2.4 × W2.9 mm		
Circuit Boards	NS Test board A	Substrate : FR-4		
	NS Reflow test Board	Substrate : FR-4		

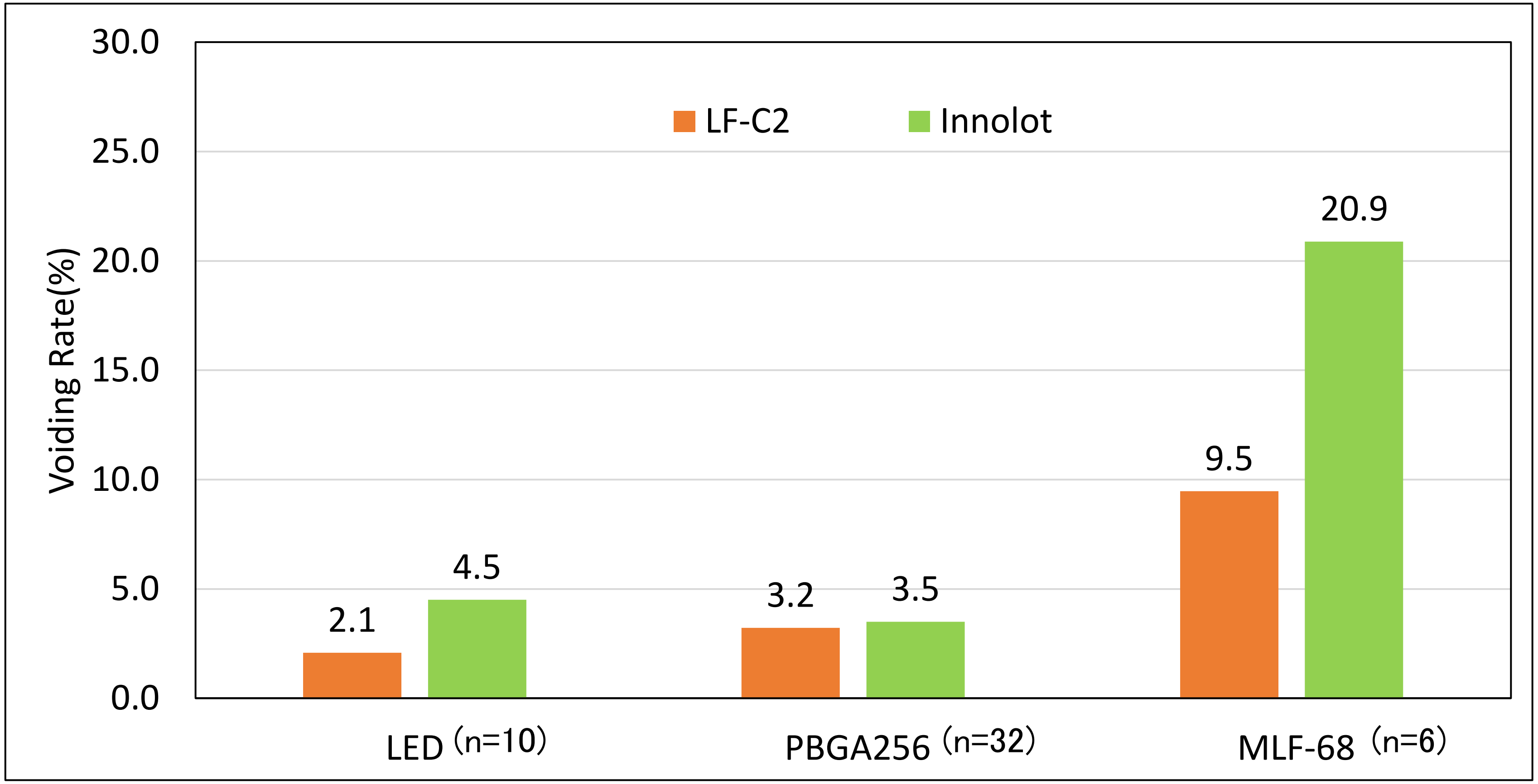
Test Items

Item	Method	Note
Void Area	Measure the voiding by area	Mean value is reported
Mid Chip Ball	Count the number of mid chip ball in CR2125	Under the component is also counted
Wettability	Count the number of good wetting terminals of SOT23 lead frame	

Sample preparation Conditions

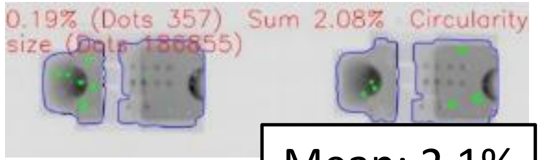
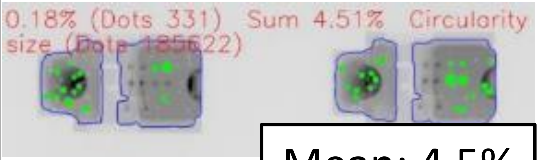
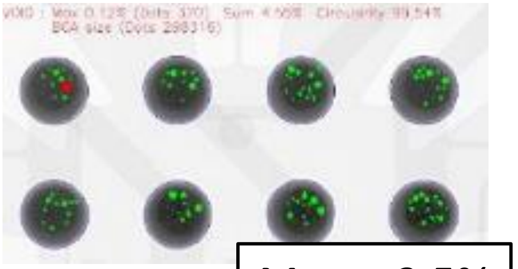
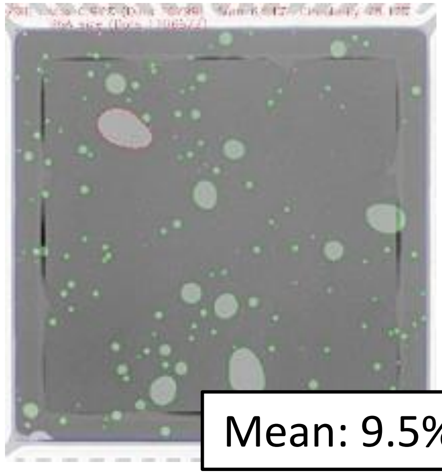
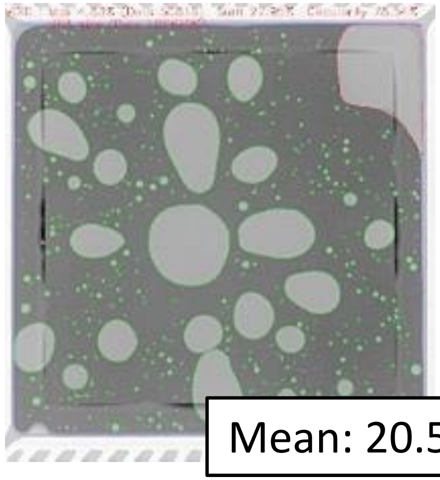
Items	
Reflow Profile	See P12
Atmosphere	Air

Test Result: Voiding Rate



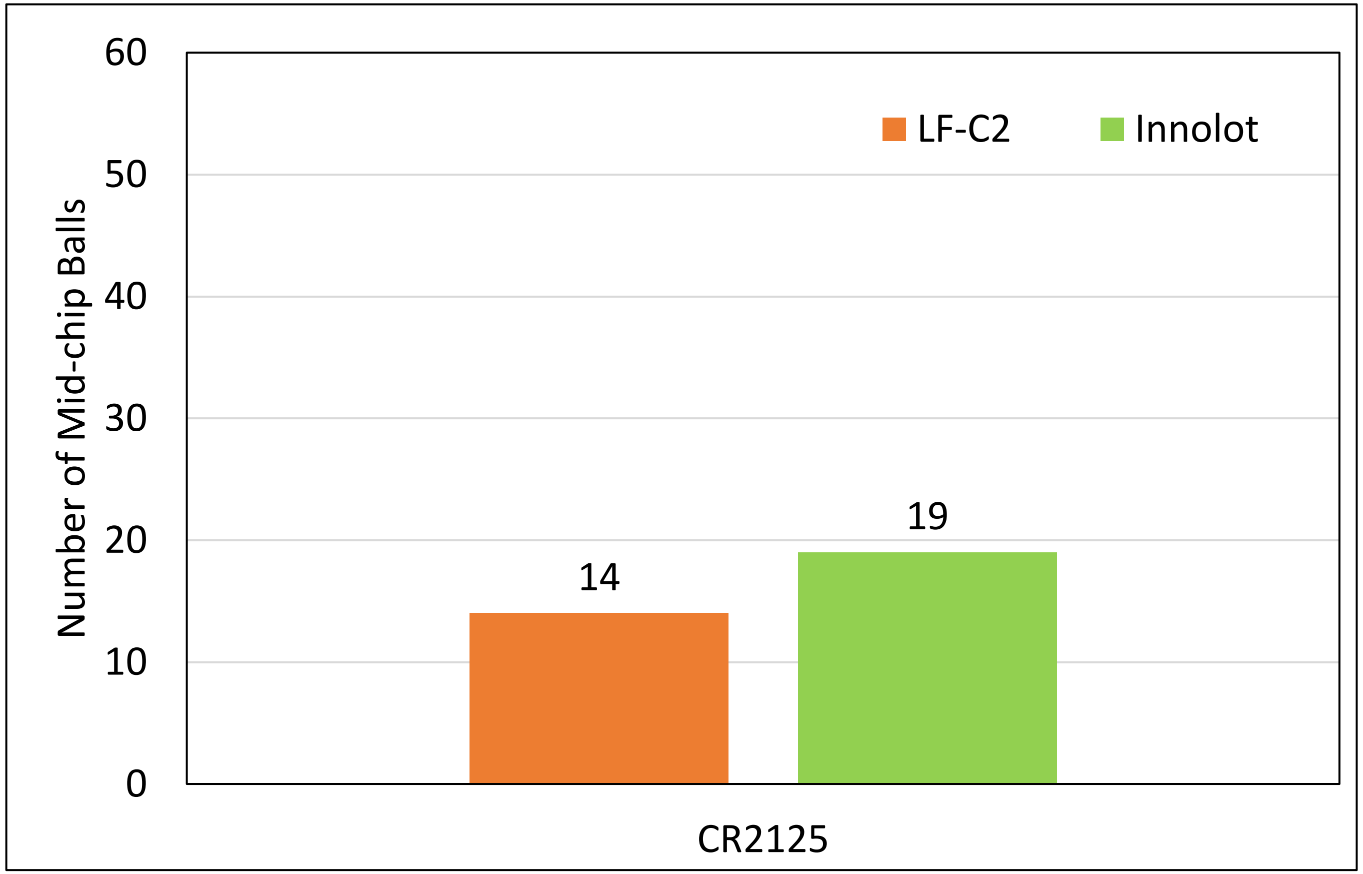
LF-C2 showed lower voiding rate than competitor in all components

Voiding Rate

	LF-C2	Alloy A
LED	 Mean: 2.1%	 Mean: 4.5%
BGA	 Mean: 3.2%	 Mean: 3.5%
MLF	 Mean: 9.5%	 Mean: 20.5%

LF-C2 showed less voiding rate than Alloy A in all components

Test Result: Mid-chip Balls

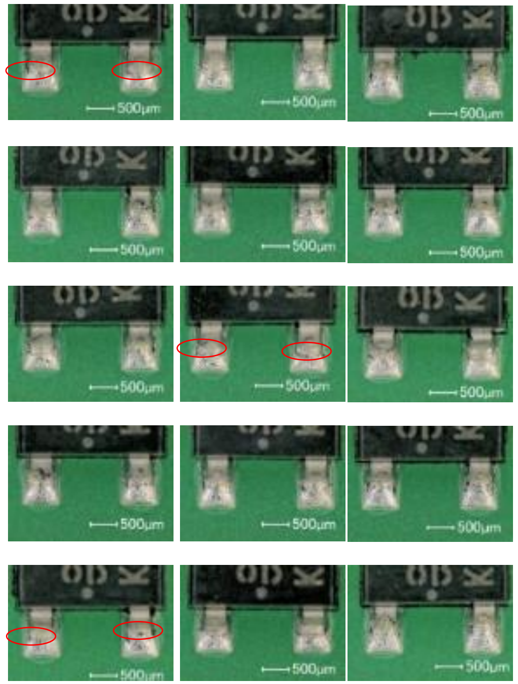
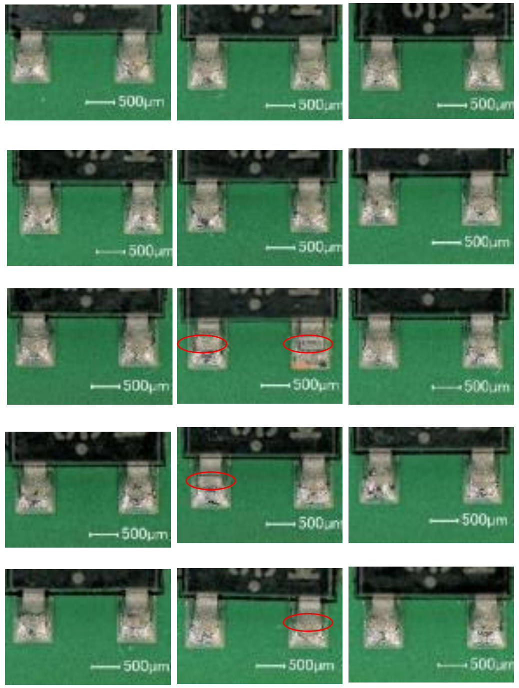


LF-C2 showed less mid-chip balls than competitor.

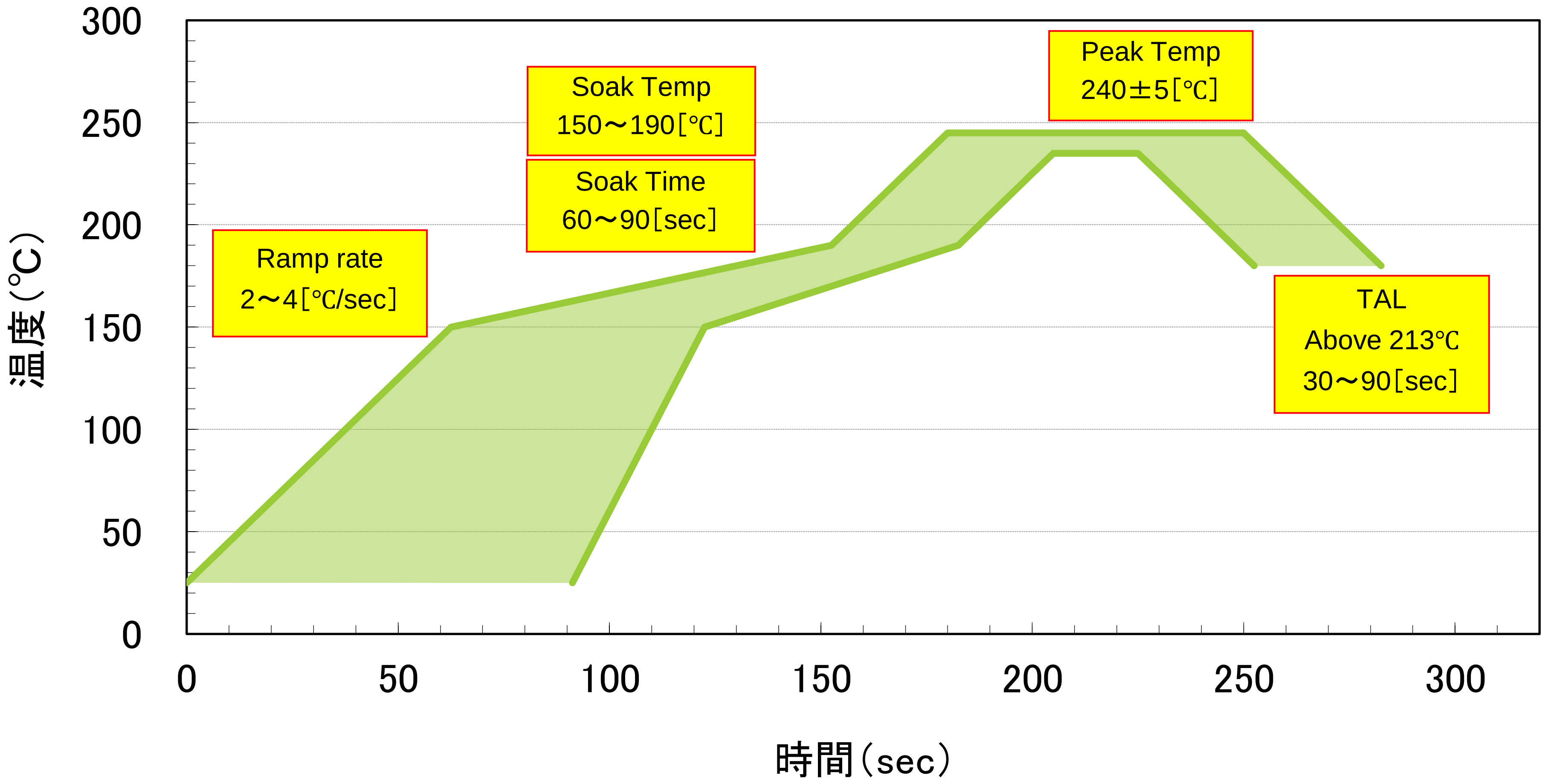
Mid-chip Ball (CR2125)

	LF-C2	Innolot
X-ray Image		
Number of balls	14	19

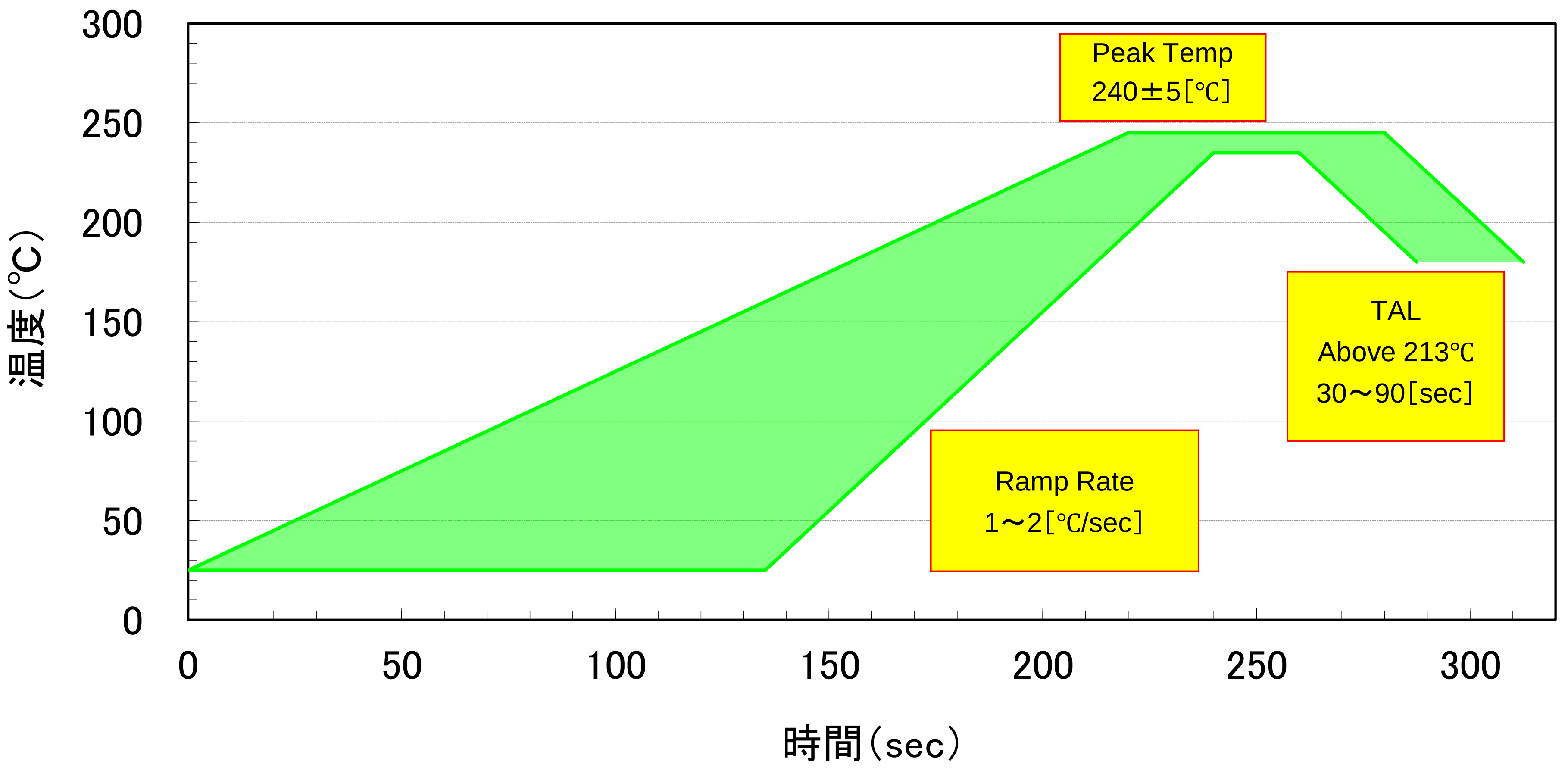
Wettability (SOT23)

	LF-C2	Innolot
Microscope Image x50		
Number of Good wetting terminals	24/30	25/30

Recommended Reflow Profile



Recommended Reflow Profile



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FCT Solder

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