JEITA's Standardization Activity of 2nd Generation Lead-Free Solder Paste

JEITA 2nd Generation Lead-Free Reflow
Solder Paste Standardization Project Group

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NihonHanda

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Henkel Japan

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KOA CORPORATION

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alpha

HITACHI
Inspire the Next

SANYO SEIKO

Project Activities

2010 | 2011 | 2012 (Year)

1st Prep PG

Discussion of project direction

2ndt Prep PG

1st Meeting

2nd Meeting

Phase 1 alloy composition proposal

3rd Meeting

4th Meeting

Evaluation test methods planning

5th Meeting

6th Meeting

Phase 1 evaluation result summary (Interim Report)

7th Meeting

Phase 2 alloy composition proposal & evaluation planning

8th Meeting

9th Meeting

10th Meeting

11th Meeting

Phase 2 evaluation result summary

12th Meeting

13th Meeting

14th Meeting

Summarize recommended compositions & write-up report

Project Action Plans

1. Obtain suggestions from the solder manufactures

Low-Ag SAC Paste

- Increase in reflow temp
- Impact on thermal fatigue and wetting

→
- **Lower temp by adding Bi in 1Ag & 0.3Ag base SAC**
- **Improve properties by adding trace elements**

Sn-Bi low-temp Paste

- Impact on shock strength
- Creep fatigue & max operating temp

→
- **Sn-58Bi & Sn-57Bi-1Ag life time cannot be estimated**
- **No improvement on high-strain impact strength. High potential, but suspended for general use**

Specialized Paste

- Effectiveness of additives
- Side effects

→
- **Research market demand**
- **Unable to narrow down. May need to be customized by application. No progress**

2. Quantification of properties using user-friendly methods

→ **Challenge towards new test methods**

3. Licensing terms for alloy candidates are RAND basis

→ **Agreed upon at the start of project**

2nd Gen. Solder Alloys Recommended by JEITA PG

Sn- 1Ag- 0.7Cu- 2Bi*

Sn-1Ag-0.7Cu-1.6Bi-0.2In

Why?

1. Compatible with SAC305 reflow profile
2. Similar mechanical properties and impact strength as SAC305

However, although not critical, below characters were observed:

1. High-strain thermal fatigue properties are slightly lower than SAC305
2. Stress can not be applied during cooling due to a gap between solidus & liquidus temperature

Evaluation: Alloys & Test Parameters

❑Direction of 2nd phase evaluation

Reflow Temp.

Low-Ag SAC

(1)Verification of effect on lower reflow temp (Bi & In)

☐ Lower limit temp check
☐ Profile Wetting Test

Bi： 0～3%
In： 0～0.5%
Determined based on the preliminary study of SAC+Bi

(2) Identification & Quantification of deteriorated properties

☐ Izod Test
☐ HS Test
☐ TSOP Peel Strength
☐ Ball Shear Strength

Alloys

○ *Sn-0.3Ag-0.7Cu + Bi + α*
○ *Sn-1.0Ag-0.7Cu + Bi + α*

(3) Improvement of deteriorated properties

☐ Effects of elemental additions (Bi+α)

Required Properties

◎ SAC305

Tested Parameters and Alloys (Details)

Evaluation Parameters

- **Melting Point & Reflow Temperature**
  - **Reflow Profile & Requirement**
  - **Melting Test (Reflow Test)**
  - **Wetting Test**
- **Mechanical Strength Test**
  - **Chip shear test**
  - **High-speed shear test (Izod)**
  - **Impact bending test**
  - **Limit bending test**
  - **Thermal shock and fatigue test**

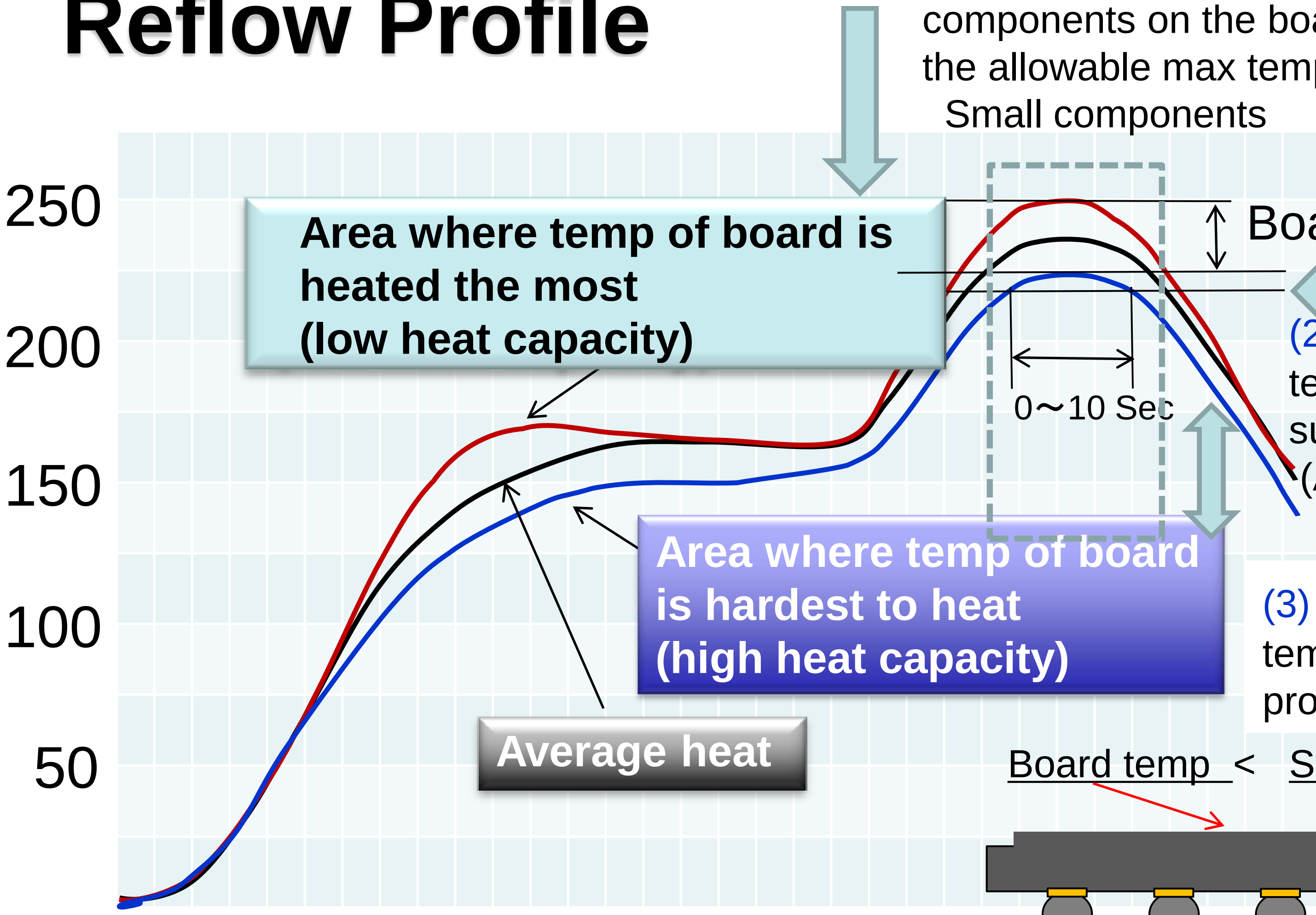
Evaluation Solder Candidates

No.	Sn	Ag	Cu	Bi	In	Other	Remarks
1	Bal	3	0.5				Ref: SAC305
2	Bal	1	0.7	1.6	0.2		Senju alloy code: M40
3	Bal	1	0.7				Evaluate the effects of Bi-doped SAC107
4	Bal	1	0.7	2			
5	Bal	1	0.7	3			
6	Bal	1	0.7	1			Evaluate the effects of In-doped SAC107+1Bi
7	Bal	1	0.7	1	0.2		
8	Bal	0.3	0.7	3			Evaluate the effects of In-doped SAC0307+3Bi
9	Bal	0.3	0.7	3	0.2		
10	Bal	1	0.5	3		Ni 50ppm	Evaluate the effects of Ni-doped SAC107+3Bi
11	Bal	1	0.7	1.5	0.2	+α	Harima Chemicals codes: LS1.0A1, LS1.0A2
12	Bal	1	0.7	1.5	0.5	0.5Sb +β	Evaluate the effects of Sb addition and In increase

Melting Point & Reflow Temperature

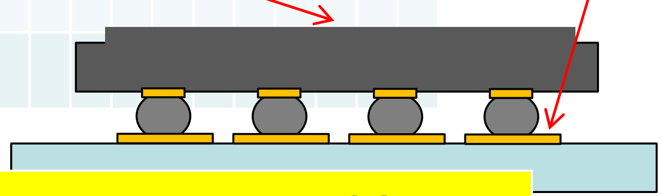
Reflow Profile

(1) T_P : Set the peak temp so that all components on the board must not exceed the allowable max temp.
Small components



(2) T_{min} : Entire soldering temp of board must meet sufficient min temp (Above X℃ & Y sec)

(3) T_{margin}: Must consider temp margin for production line (min 5℃)



(Ex.) T_{min} : $T_P 260℃ - \Delta T 20℃ - T_{margin} 5℃ = 235℃$

$T_P 245℃ - \Delta T 15℃ - T_{margin} 5℃ = 225℃$

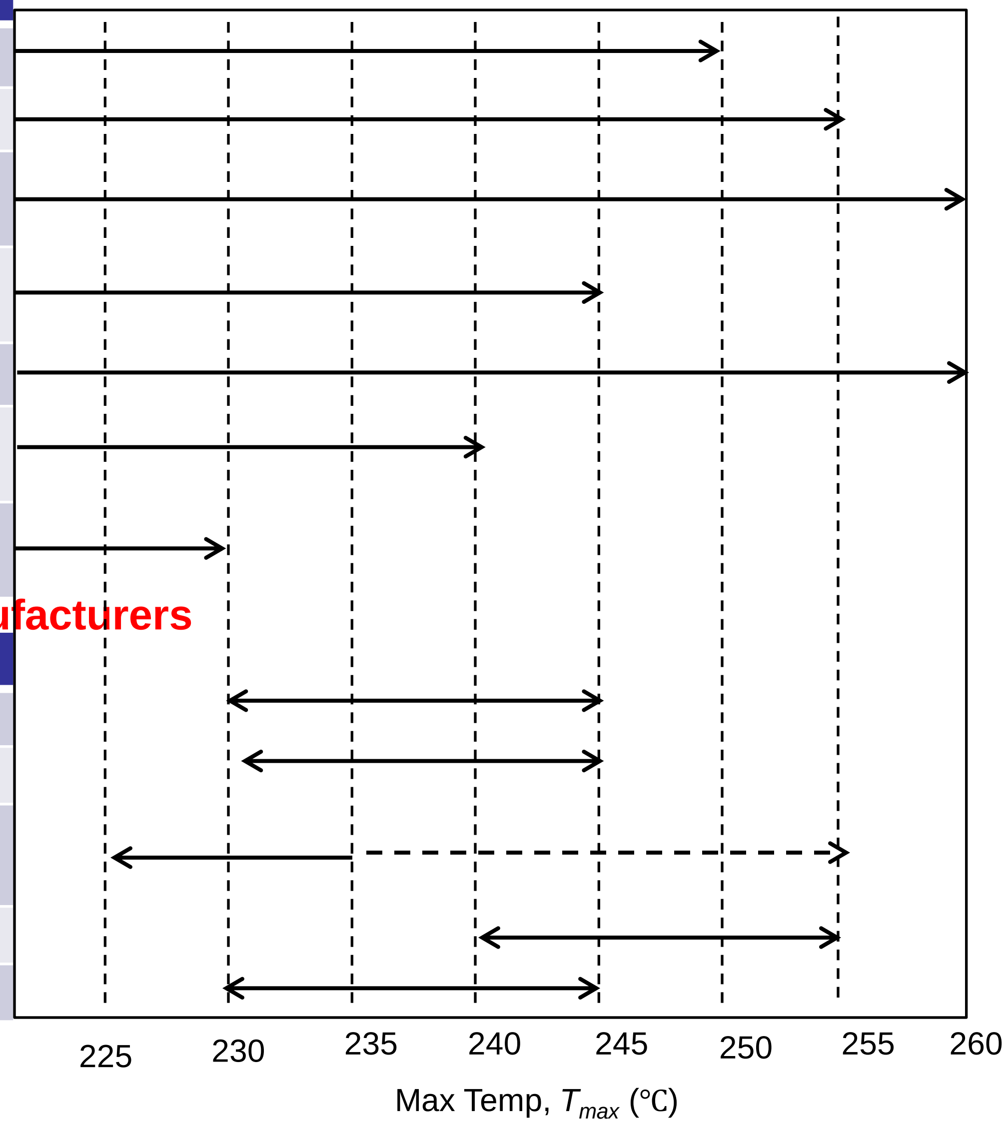
Reflow Temp Requirements

Reflow heat resistance of components

Parts/Standards	Temp x Time, T_{max}	Max, T_{max}
IEC C60068-2-58	220℃ X 60～90s	250℃
IEC C60068-2-58	220℃ X ≦60s	255℃
IPC/JEDEC J-STD 020D small & thin	217℃ X 60～150s	260℃
IPC/JEDEC J-STD 020D large & thick	217℃ X 60～150s	245℃
Semiconductor company“T”	230℃ X 30～50s	260℃
Al electrolytic capacitor（medium)	220℃ X ≦30s	240℃
Al electrolytic capacitor（large)	217℃ X ≦20s	230℃

Solder reflow temp used by assembly manufacturers

Mfr	Min, T_{min}	Max, T_{max}	Diff, ΔT
S	230℃	245℃	15℃
P	232℃	245℃	13℃
T	Solder liquidus +(5~10℃)	Component heat resistance -(5~10℃)	-
A	240℃	255℃	15℃
F	230℃	245℃	15℃

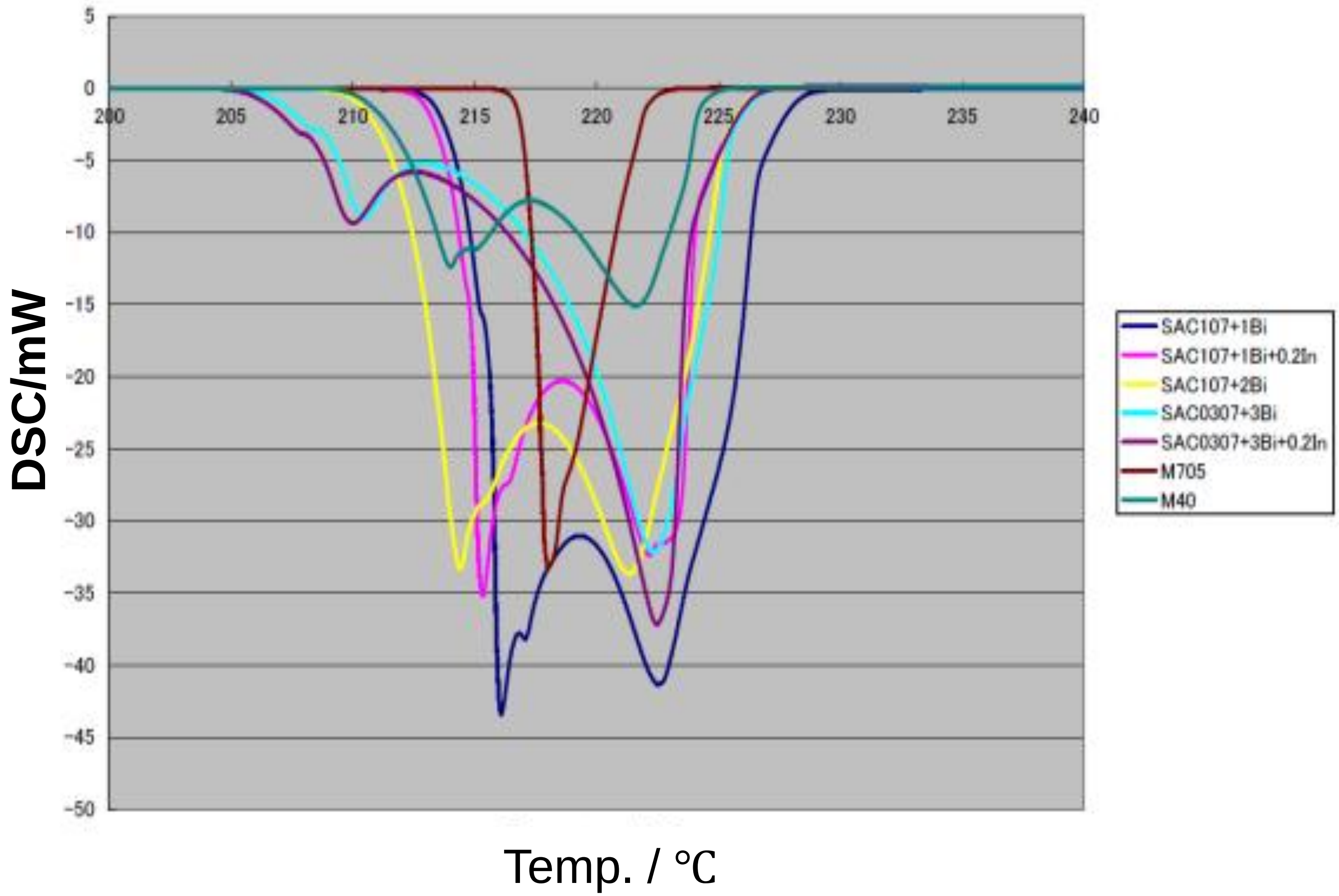


Summary of Temp. Requirements

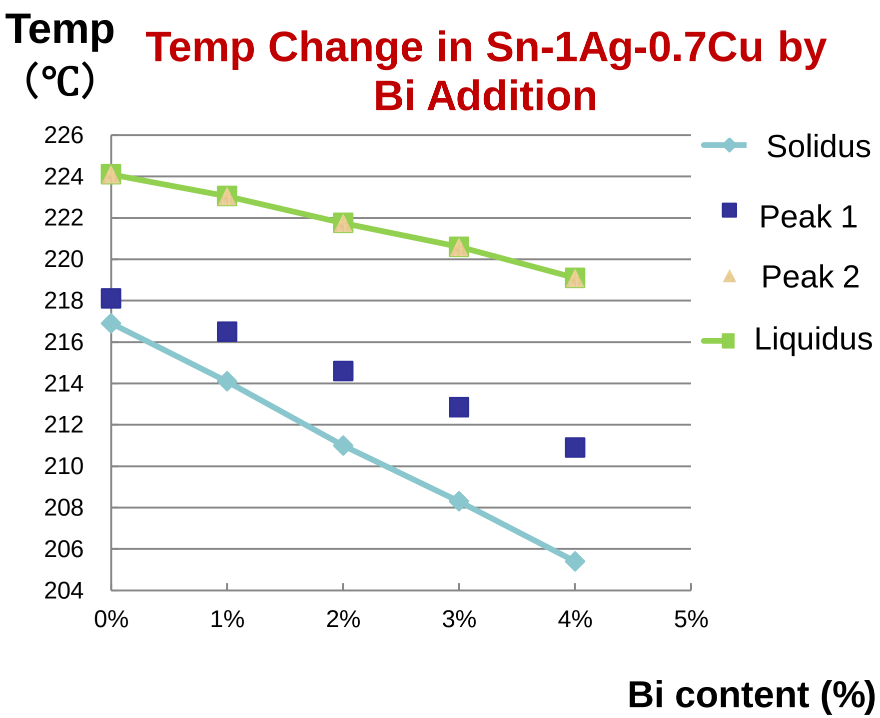
1. Reflow Limits should be defined as follows:
   Highest set temp.= Heatproof temp. of parts－Temp. variation
   Lowest set temp.= Liq. line temp. of solder + Temp. variation
2. Highest allowable surface temp. of parts is:
   ・260℃ for typical semiconductors
   ・230℃ for some large capacitors
   and so on
3. It was concluded that the control of the reflow temp. profile was important and critical

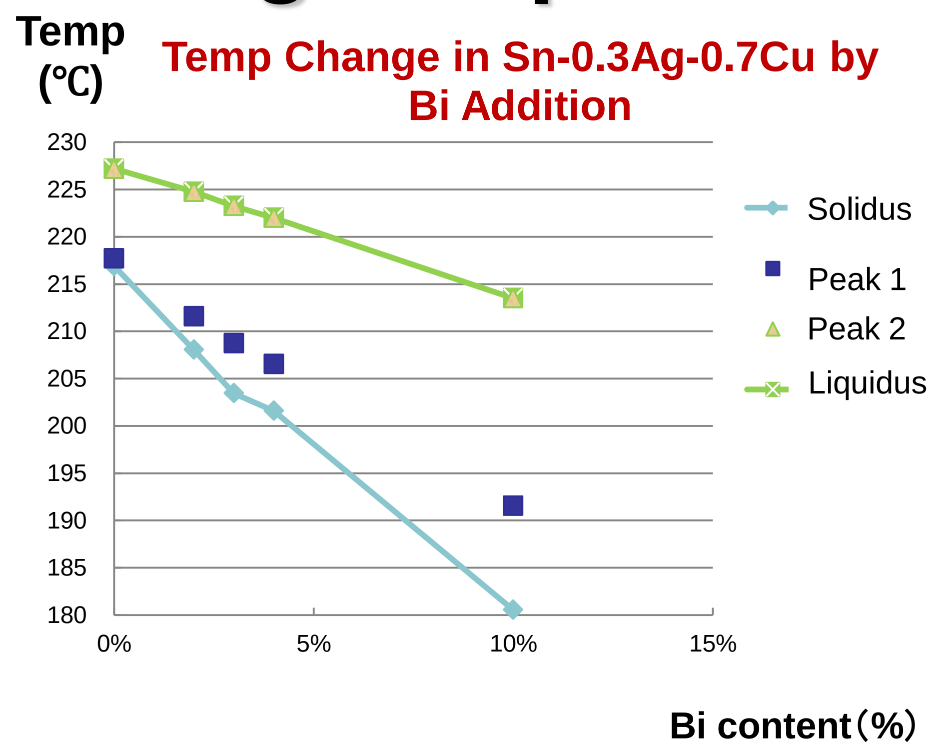
Melting & Wetting Test

Melting Temperature Measurements
(Ex; Results of DSC)



The Effect of Bi on Melting Temperature





- When 1% Bi is added to 1Ag alloy, solidus and liquidus temp will drop 3ºC and 1ºC respectively.
- When 1% Bi is added to 0.3Ag alloy, solidus and liquidus will drop 3.6ºC and 1.3ºC respectively.

Lower Limit Temperature in Reflow(1)

【Conditions】

Equipment：Reflow simulator (Sanyo Seiko SP-5000DS)

Component : 8mm dia. coil

Board size : 30mm x 30mm

Component location : Center

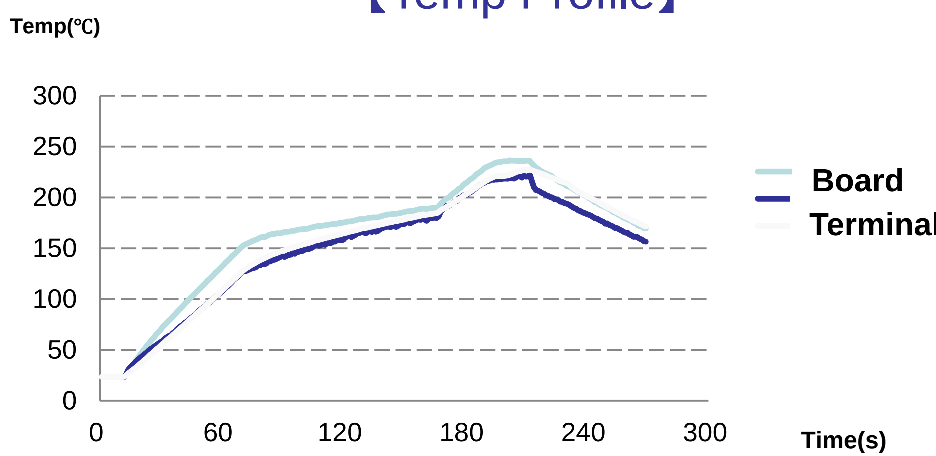
Soldering Method : Screen print

【Method】

After heating with reflow simulator, verify fillet formation on the 8mm coil

○：Fillet formed **×：Fillet not formed**

【Temp Profile】



Example: 225℃ or higher for 10s

Lower Limit Temperature in Reflow

Actual measurement (others are estimate)

Solder Composition					Sol-dus (℃)	Liq-dus (℃)	ΔT (℃)	Reflow Temp.(℃) (Hold for 10 sec.)										
Sn	Ag	Cu	Bi	In				220	221	222	223	224	225	226	227	228	229	230
Bal	3	0.5			217	218	1	×			○	○	○	○	○	○	○	○
Bal	1	0.7	1.6	0.2	210	222	12	×	×	×	×		○	○	○	○	○	○
Bal	1	0.7			217	224	7	×	×	×	×	×	×	×	×			○
Bal	1	0.7	1		214	223	9	×	×	×	×	×	×		○	○	○	○
Bal	1	0.7	1	0.2	213	223	10	×	×	×	×	×	×		○	○	○	○
Bal	1	0.7	2		211	222	11	×	×	×	×		○	○	○	○	○	○
Bal	1	0.7	2		208	221	13	×	×	×	×		○	○	○	○	○	○
Bal	0.3	0.7	2		203	223	20	×	×	×	×	×	×		○	○	○	○
Bal	0.3	0.7	2	0.2	206	223	17	×	×	×	×	×	×		○	○	○	○

Summary of Lower Limit Temperature

(Optical observation)

Against lower limit (230ºC) reflow profile:

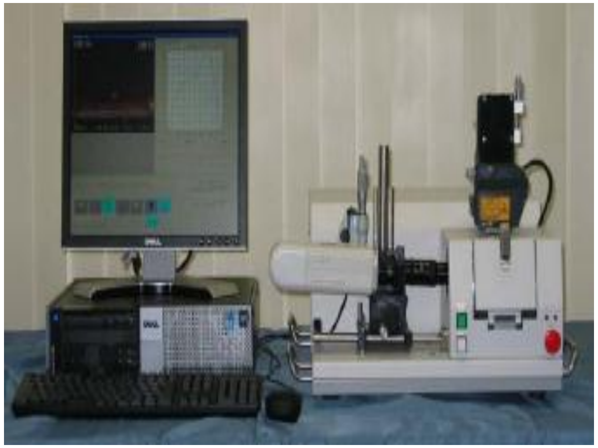
- SAC305 : more than 5ºC margin
- 107+2~3Bi : 5℃ margin ensured
- (M40) : 5℃ margin ensured
- SAC107+1Bi : Margin decreased to 3ºC
- SAC107 : No margin

Quantitative Approach

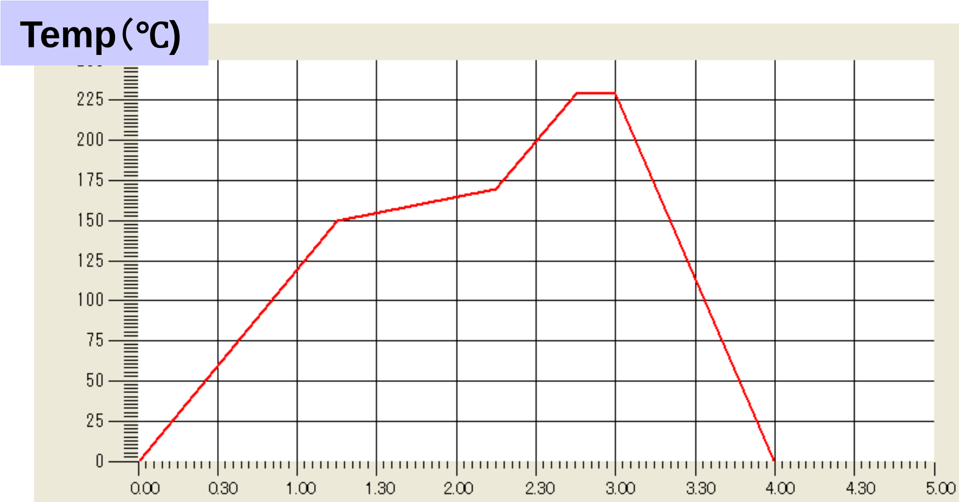
Wetting Test Method

<u>Displacement wetting test by profile heating</u>

- Possible to compare wetting values using Cu coupon
- Possible to measure the temp & time at the start and the completion of wetting



Apparatus

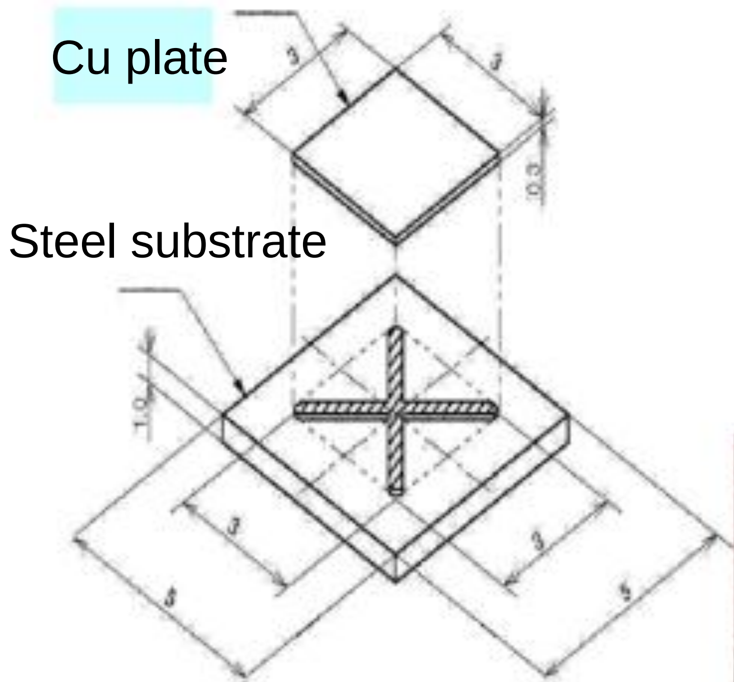


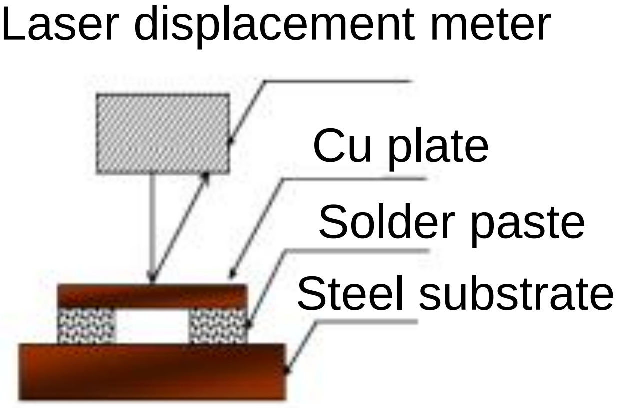
STEP	1	2	3	4	5	6
Time(min)	0.00	1.15	1.00	0.30	0.15	1.00
Temp.(℃)	0	150	170	230	230	0
Temp./Grad.(℃/s)	0	2	0.3	2	0	-3.8

Temperature profile of wetting test

Test Piece

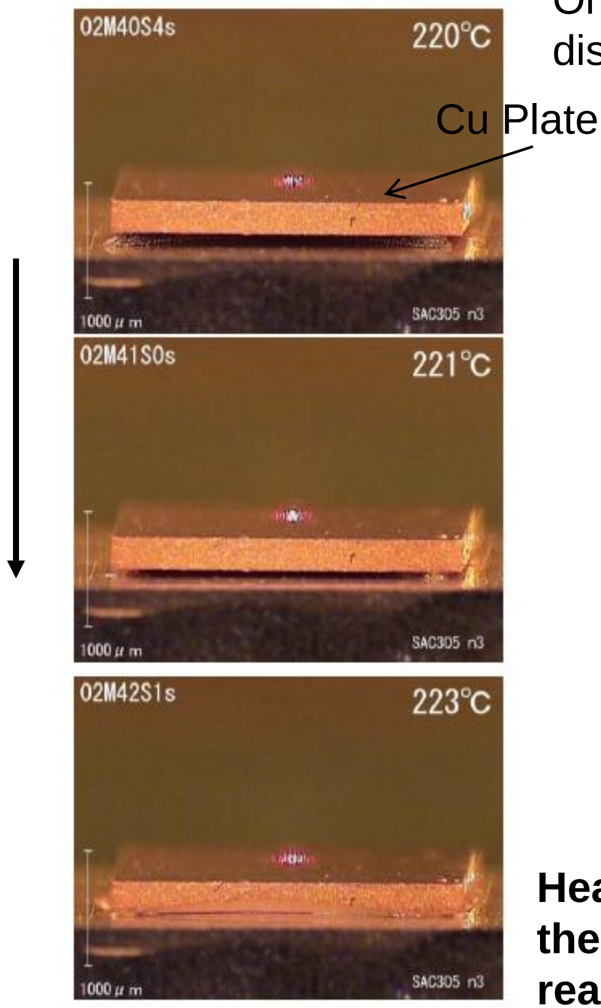
Steel substrate: 5 mm-square, t=1.0 mm
Copper piece: 3 mm-square, t=0.3 mm
(Weight: 24 mg)
Solder paste print thickness: 120±10 μm
Mount height of copper piece: 90±10 μm

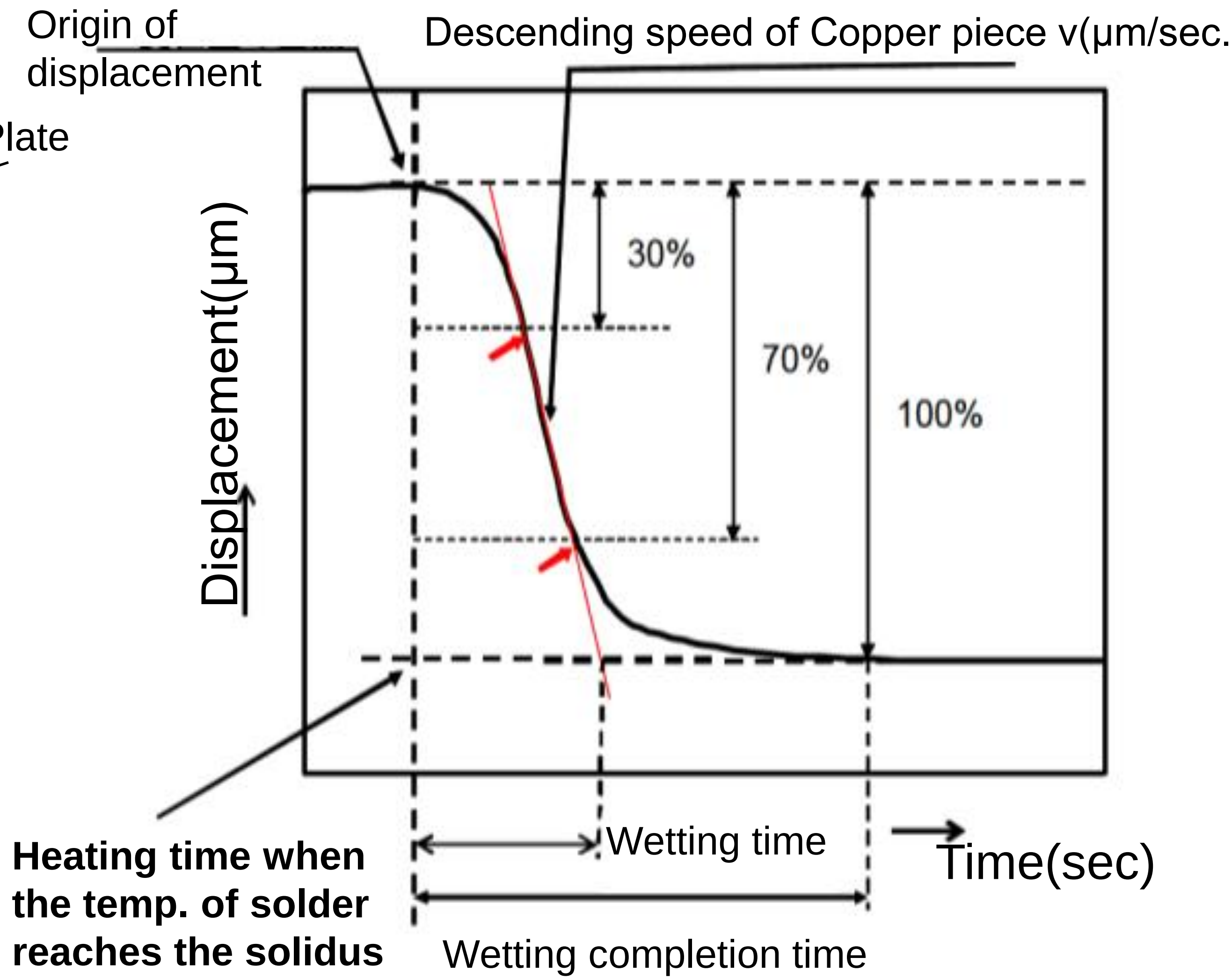




Degreasing → Acid washing →Drying

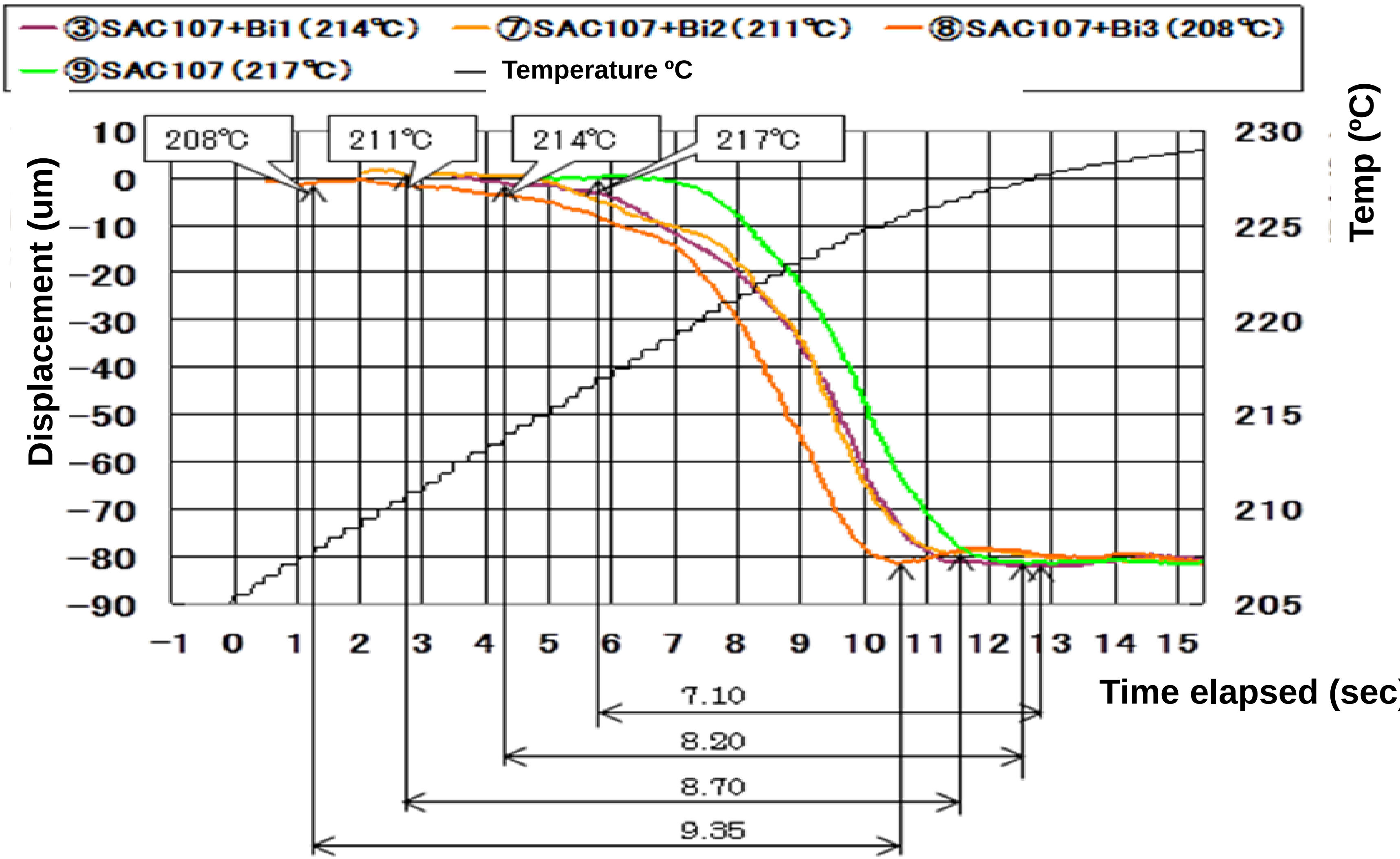
Evaluation Method





Schematic diagram of result(Displacement/Time relationship)

Ex. of Test Results



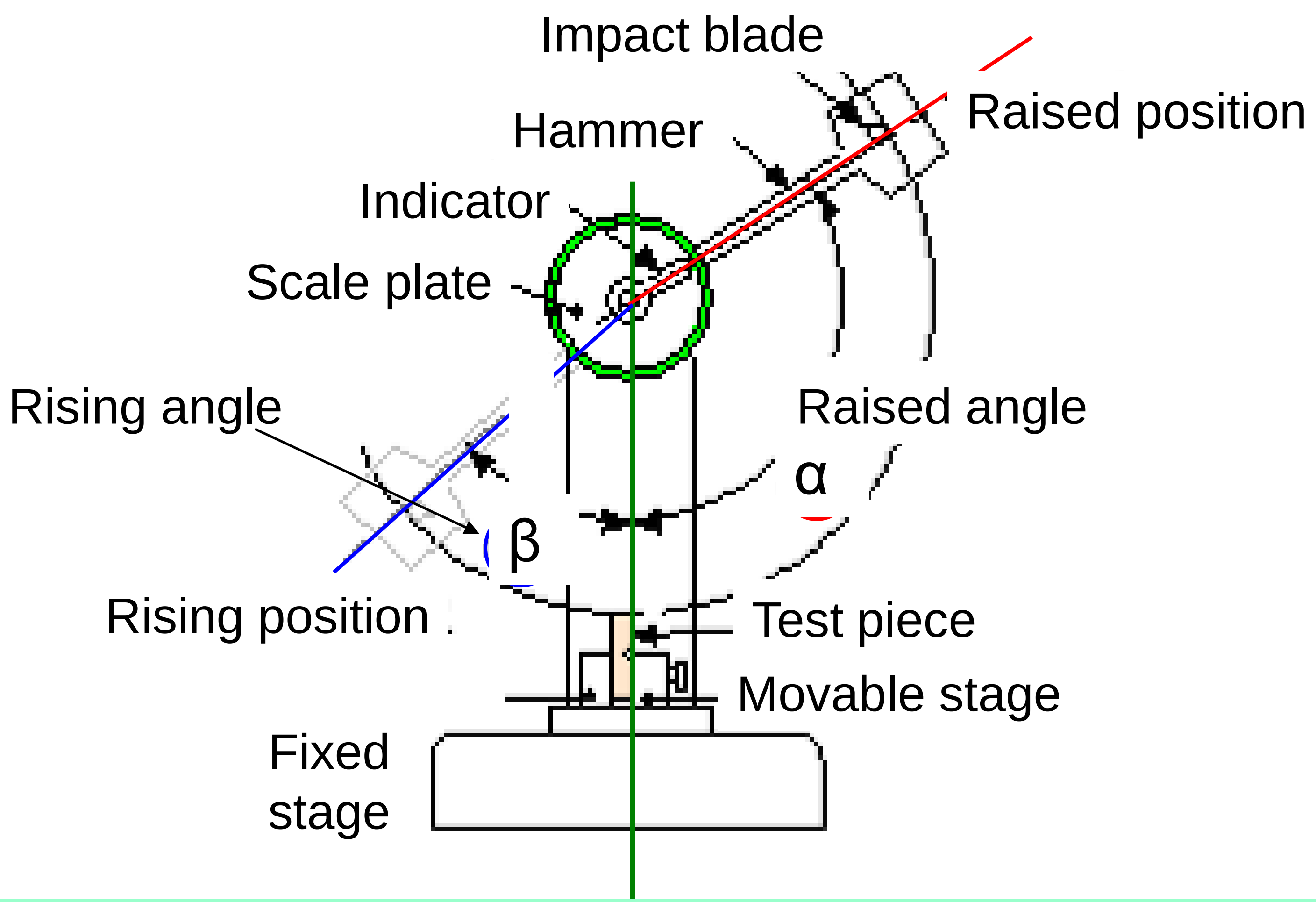
Summary of Wetting Test Results

- By Bi addition, wetting start time & temp. become shorter and lower.
- Wetting finishing time & temp. also become shorter and lower.

As the results, the wetting property (solderability) was improved by Bi additions.
By Bi addition, we can achieve almost the same soldering temp. profiles as the SAC305 though using low Ag content(1%Ag) SAC solder.

Mechanical Strength Test

Izod Impact Test

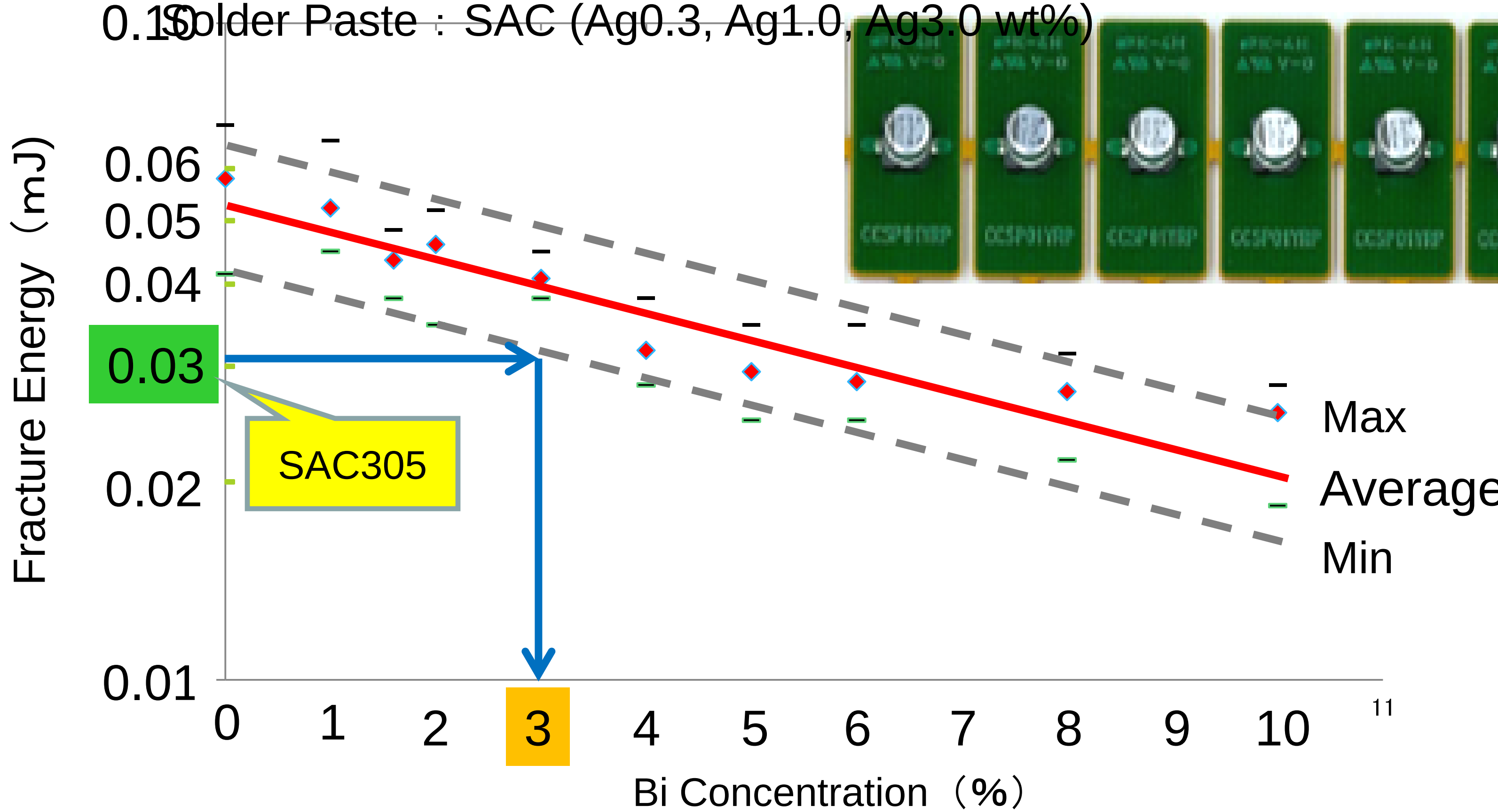


Fracture energy is obtained by the Izod Impact Test

The Effect of Bi Addition using Izod Impact Test

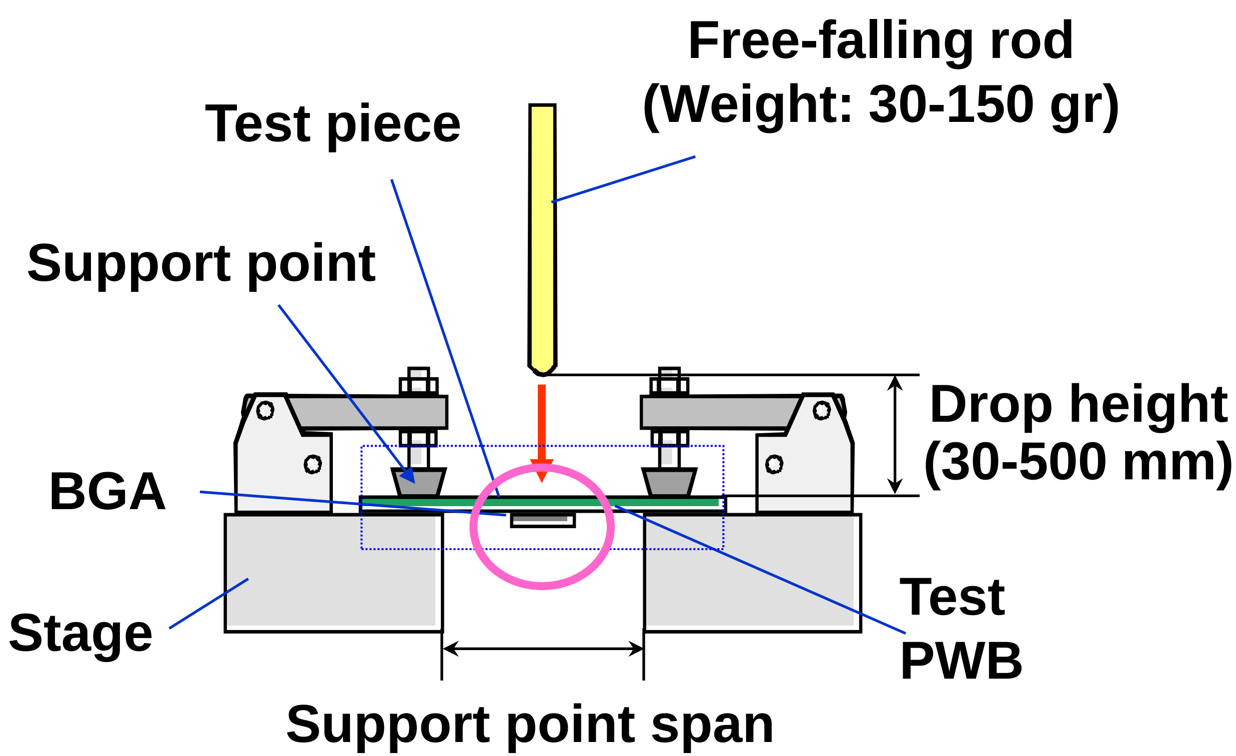
Component： Dia. 5mm Cap Aluminum (Nichicon UWT1C220MCR1GB)

Solder Paste：SAC (Ag0.3, Ag1.0, Ag3.0 wt%)



To meet SAC305 level, Bi content in SACB107 α must be 3wt% Max

Substrate Bending Test (IBT)

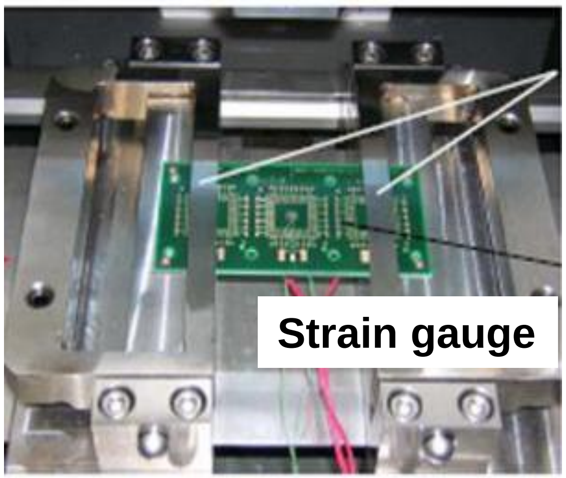


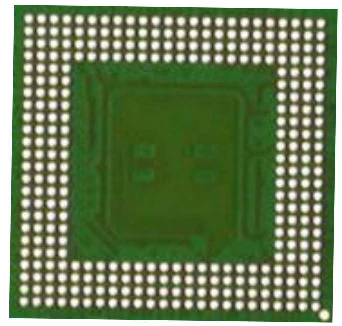
(ED-4702B)
Rod Drop Impact Test :
Impact Bending Test (IBT)

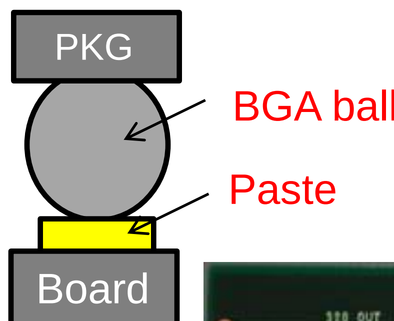
Evaluation can be done by measurement of strain and rod dropped numbers

Principle and apparatus

Substrate Bending Test (IBT)

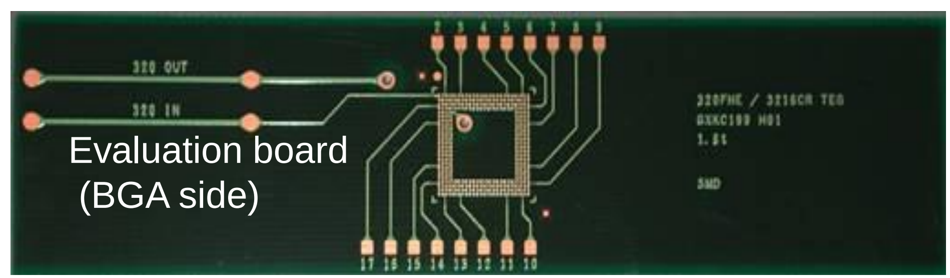






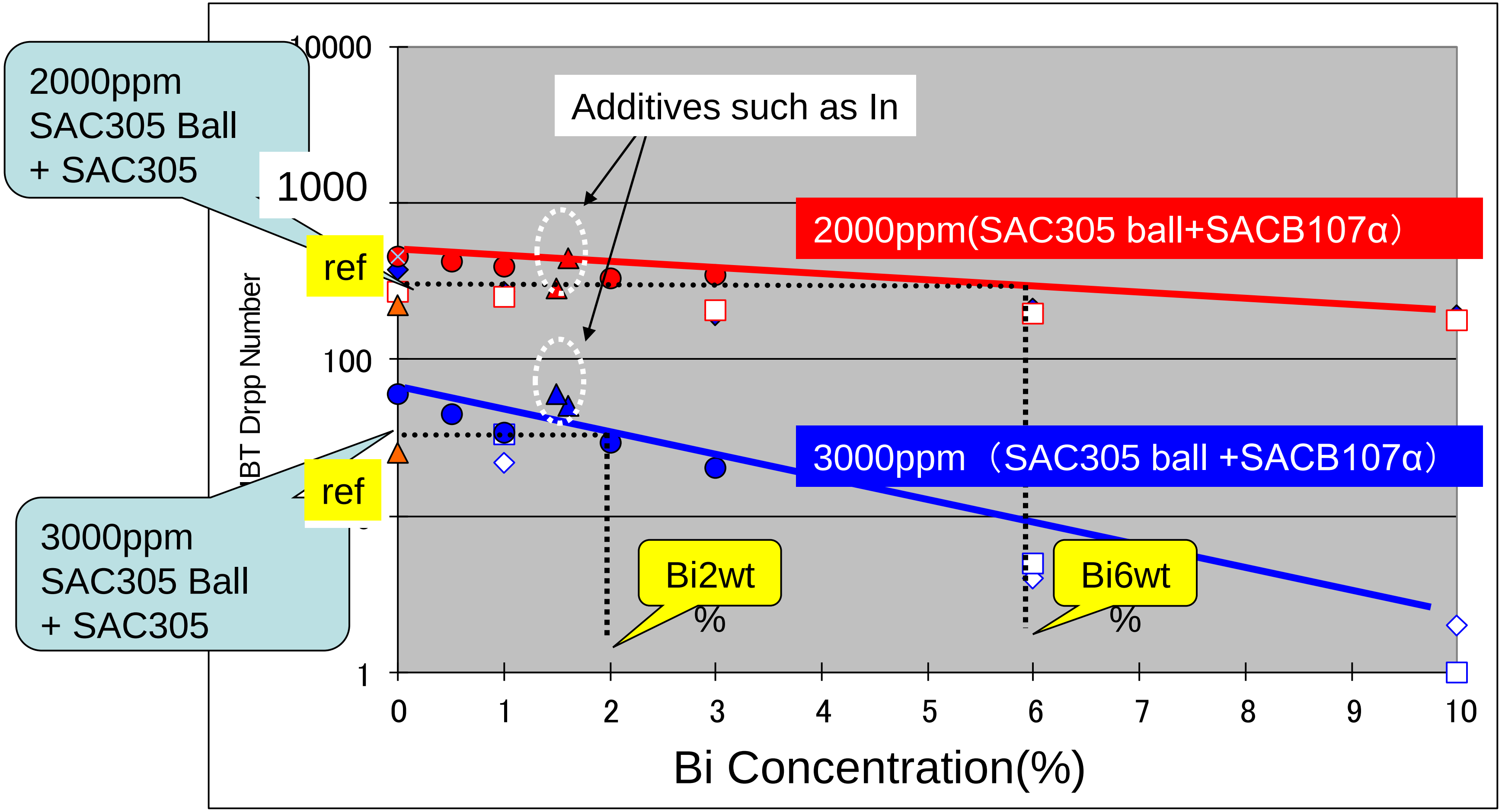
<Board>
Material：FR4
Pad：Cu-OSP
Outline：30x120x1.6mmt

<Sample>
BGA：1313-224 pins(0.5mP)
PKG pad：Electrolytic Ni/Au
Ball alloy: SAC305 &SAC105
Ball dia：0.3mm
<Reflow Profile>
Peak 235℃



Test Piece and placement

IBT Evaluation Results



Summary of Izod & IBT Tests

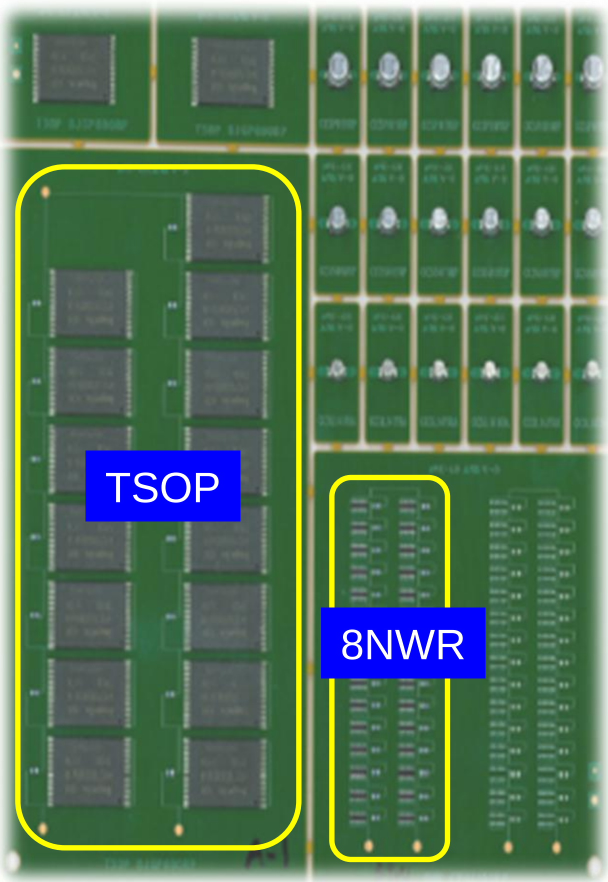
(1)The addition of Bi to SAC107 should be limited to 3 mass% Max. by the results of Izod impact tests.

(2)For SAC305 ball & SACB107 paste combination, SAC305 equivalent level can be met when Bi is 6% for IBT (2000ppm) and 2% for IBT(3000ppm).

(3)For high-impact IBT (3000ppm strain), additives such as In are found to be effective.

Thermal Fatigue Test

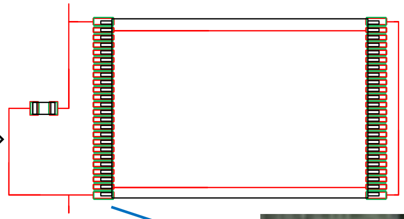
Sample of Thermal Fatigue Test



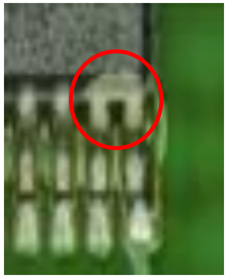
Components:

(1)Eight-ganged network resistor (8NWR)

(2) TSOP



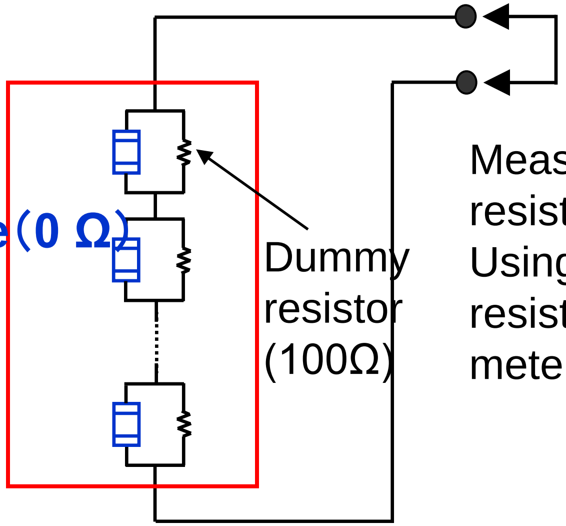
Short caused by Ag paste



Board	: FR-4
Size	: 160 x16mm
Thickness	: 1.6mm
Screen thickness	: 120μm

Test board and specimen

Method of Thermal Fatigue Test



Test Conditions:
－25～125℃(20min./cyc.)
～1500 cycles

Procedure:

Connect evaluation sample & dummy resistor (1608 size 100Ω) in parallel, then connect n=30 in series

↓

If open is found in one sample, detect the 100Ω of dummy resistor

↓

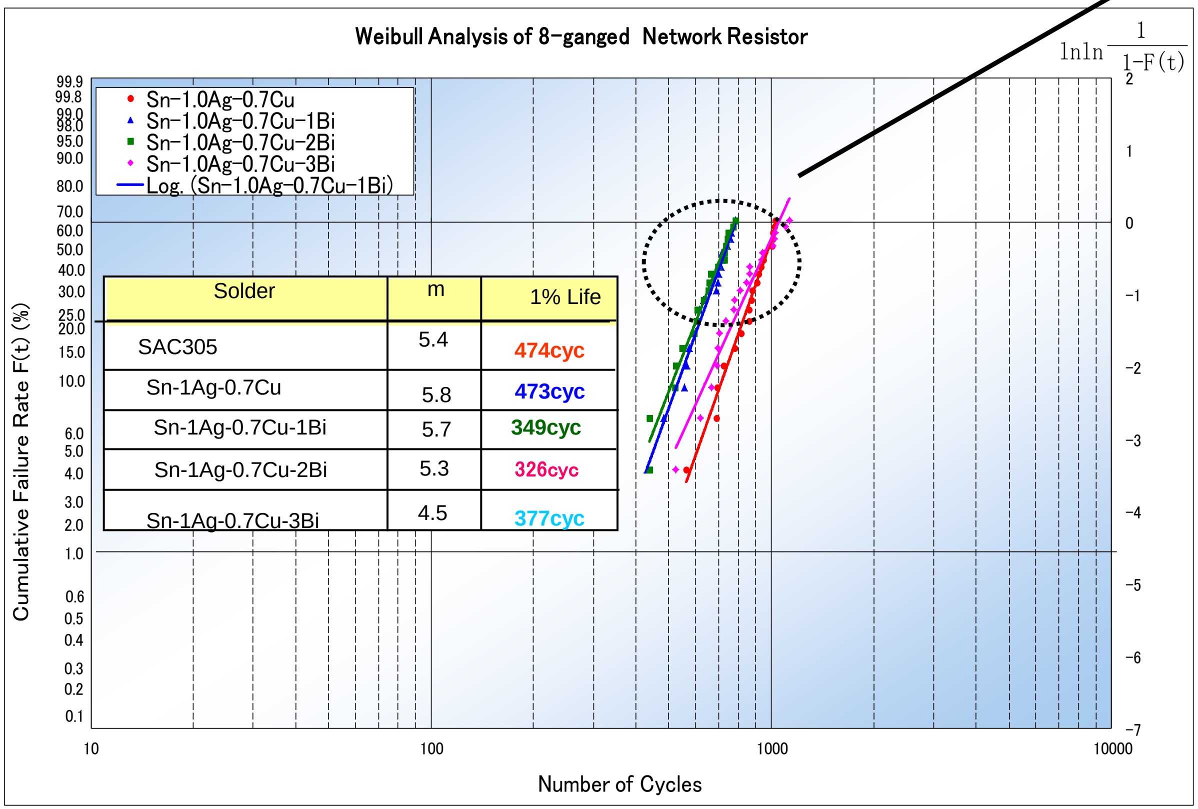
By using micro meter, detect the change in resistance and determine the cycle where cracks had occurred (electrical opens)

↓

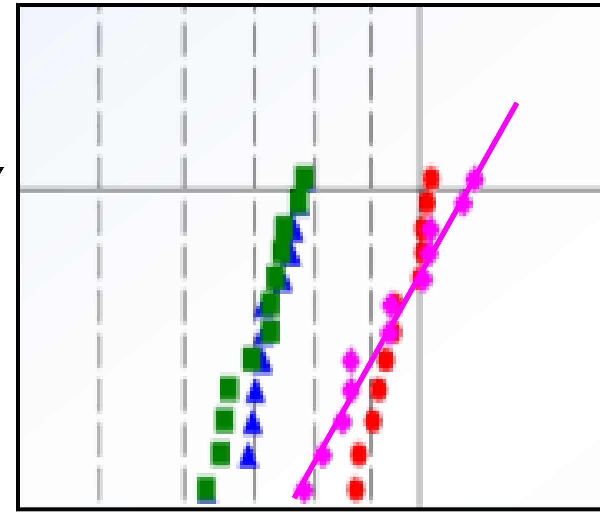
Perform Weibull analysis and compute the cycle numbers at 1% cumulative failure rate

Thermal shock test chamber

Examples of Thermal Fatigue Test Results (8NWR)



Solder	m	1% Life
SAC305	5.4	474cyc
Sn-1Ag-0.7Cu	5.8	473cyc
Sn-1Ag-0.7Cu-1Bi	5.7	349cyc
Sn-1Ag-0.7Cu-2Bi	5.3	326cyc
Sn-1Ag-0.7Cu-3Bi	4.5	377cyc

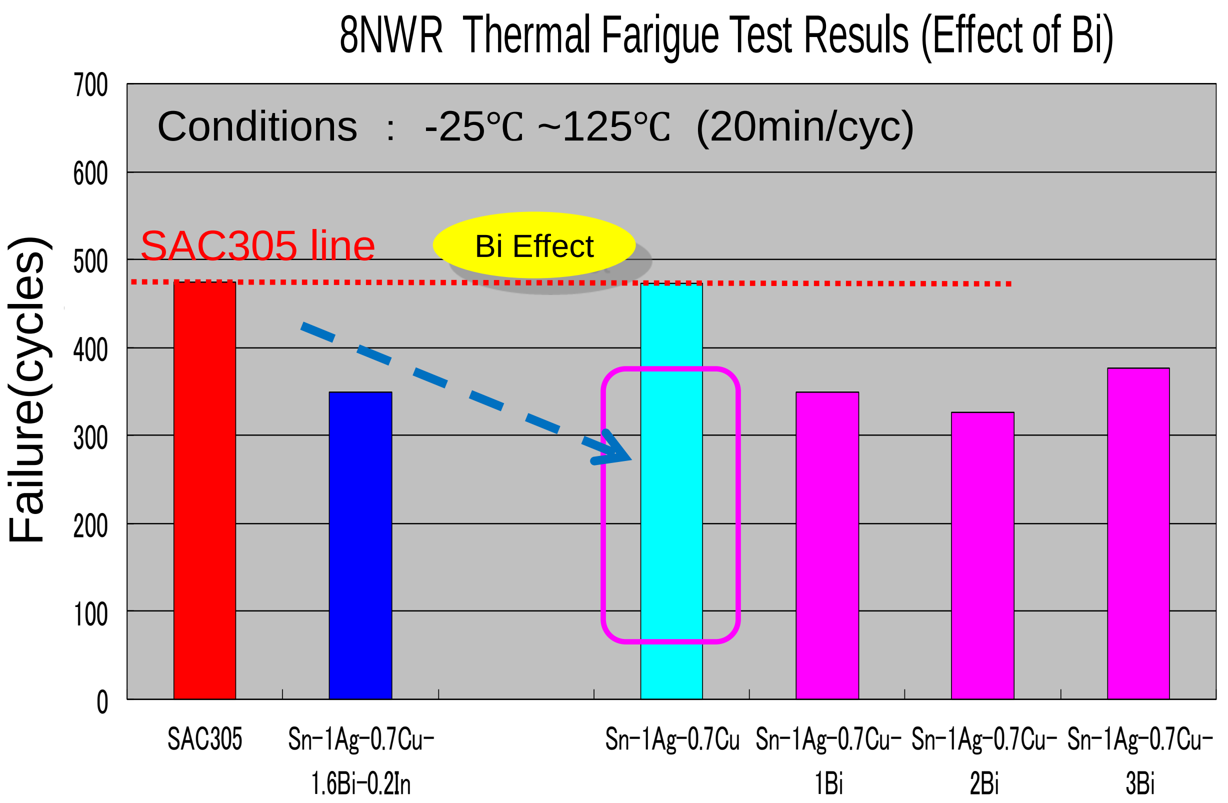


m values in the failure region

Solder	m
Sn-1Ag-0.7Cu	5.8
Sn-1Ag-0.7Cu-1Bi	6.5
Sn-1Ag-0.7Cu-2Bi	4.8
Sn-1Ag-0.7Cu-3Bi	2.8

8NWR; 8 Ganged Net Work Resister

Thermal Fatigue Test Results (8NWR)

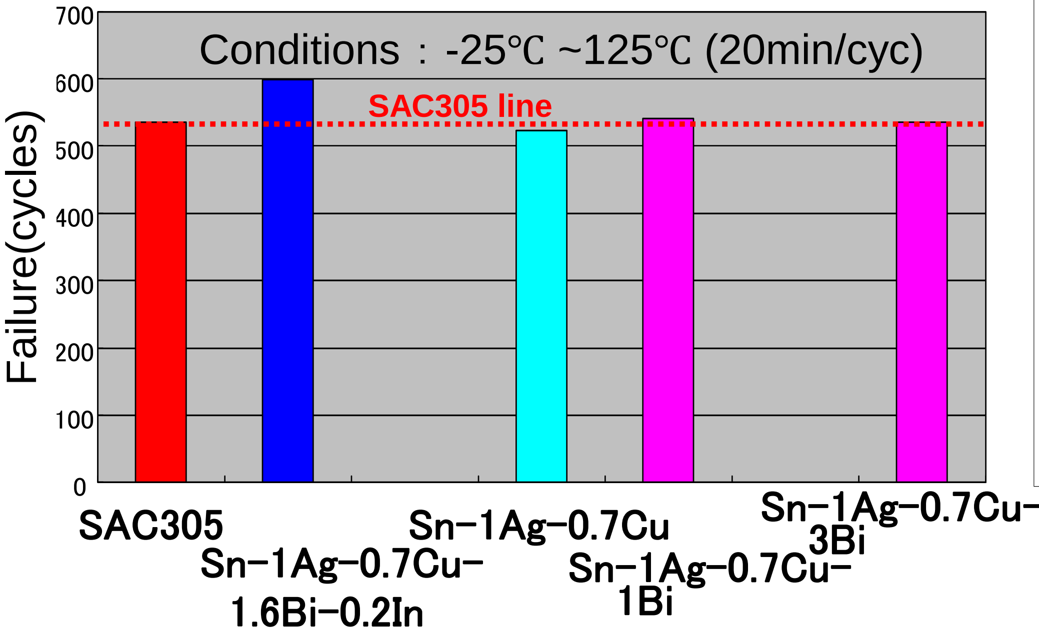


*Definition of "similar" : Nearly the same Weibull slope & cycle # at 1% cumulative failure rate is within ±10%

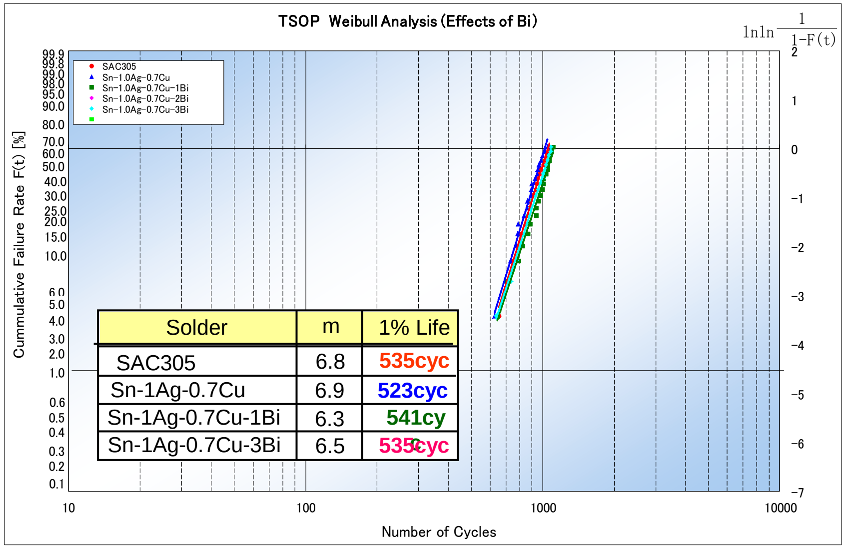
- Thermal fatigue life of Sn-1Ag-0.7Cu is similar* to that of SAC305
- The life of Sn-1Ag-0.7Cu drops by 20~30% when 1~3% of Bi is added.

※ As compared to Bi1% & Bi2%, the Weibull slope of Bi3% is different and therefore the failure mode is likely to be different

Thermal Fatigue Test Results (TSOP)



TSOP Thermal Fatigue Test Results (Effect of Bi)



Previous test results Conditions: -40℃ ~125℃ (60min/cyc)

Base Solder	B content (%)	200cyc	400cyc	600cyc
Sn-1Ag-0.7Cu	0	0/3 NG	0/3 NG	2/3 NG
	3	0/5 NG	0/5 NG	1/5 NG
	5	0/5 NG	3/5 NG	**5/5 NG**
	8	0/5 NG	4/5 NG	**5/5 NG**
	10	0/5 NG	**5/5 NG**	**5/5 NG**

Dramatic drop in life when Bi is added by 5% or more

Summary of Thermal Fatigue Test

(1) Thermal fatigue life of Sn-1Ag-0.7Cu is similar to that of SAC305

(2) Life of Sn-1Ag-0.7Cu similar when 1% & 3% Bi are added ⇒ Same results as previous small quantity testing

(3) Slight increase in life for Sn-1Ag-0.7Cu-1.6Bi-0.2In as compared to SAC305 (by 10%)

Summary & Conclusion

Selection of low-Ag SAC alloy

Based on the evaluation results, **Sn-1Ag-0.7Cu-2Bi and Sn-1Ag-0.7Cu-1.6Bi-0.2In are the recommended alloys for the low-Ag alternatives.**

Both Sn-0.3Ag-0.7Cu & Sn-1.0Ag-0.7Cu are potential candidates for the alternative alloys. However, the lowest allowable heating temp. is the major weakness of these alloys. According to the test results, when the peak temp is set at 230℃ the following can be summarized against the melting temp limit.

1. **The current SAC305 has a margin of 5℃＋α**
2. **SAC107 has no margin at the lower limit**
3. **SAC107 + 2%Bi ensures a margin of 5℃**

Low-temp and specialized alloys

This project has been suspended because industry-wide standard alloy cannot be identified. We look forward to the developmental activities by others.

Project Activities

Leader : Koji Serizawa
Sub-leader : Kenichi Tomitsuka

Committee Members:
Alps Electric, Casio Computer, Cookson Electronics, KOA, Sanyo Seiko, Senju Metal Industry, Sony, Tamura Corp, Techno Office Yamamoto, Toshiba, Nihon Genma, NEC, Nihon Handa, Nippon Filler Metals, Harima Chemicals, Panasonic, Hitachi, Fujitsu Laboratories, Fujitsu Advanced Technologies, Henkel Japan, Murata Manufacturing Co, Renesas Electronics

Meeting	Date	Activity
1st PG Prep Meeting	May 2010	Discussion of project direction
2nd PG Prep Meeting	June 2010	
1st Meeting	Aug. 2010	Phase 1 alloy composition proposal
2nd Meeting	Sep. 2010	
3rd Meeting	Nov. 2010	Evaluation test methods planning
4th Meeting	Jan. 2011	
5th Meeting	Mar. 2011	Phase 1 evaluation result summary
6th Meeting	May 2011	
7th Meeting	July 2011	Phase 2 alloy composition proposal & eval planning
8th Meeting	Sep. 2011	Phase 1.5 evaluation & release of interim report
9th Meeting	Nov. 2011	
10th Meeting	Jan. 2012	Phase 2 evaluation result summary
11th Meeting	Apr. 2012	
12th Meeting	May 2012	
13th Meeting	Aug. 2012	Summarize recommended compositions & write-up report
14th Meeting	Oct. 2012	

Review of Interim Report (Phase 1 Evaluation)

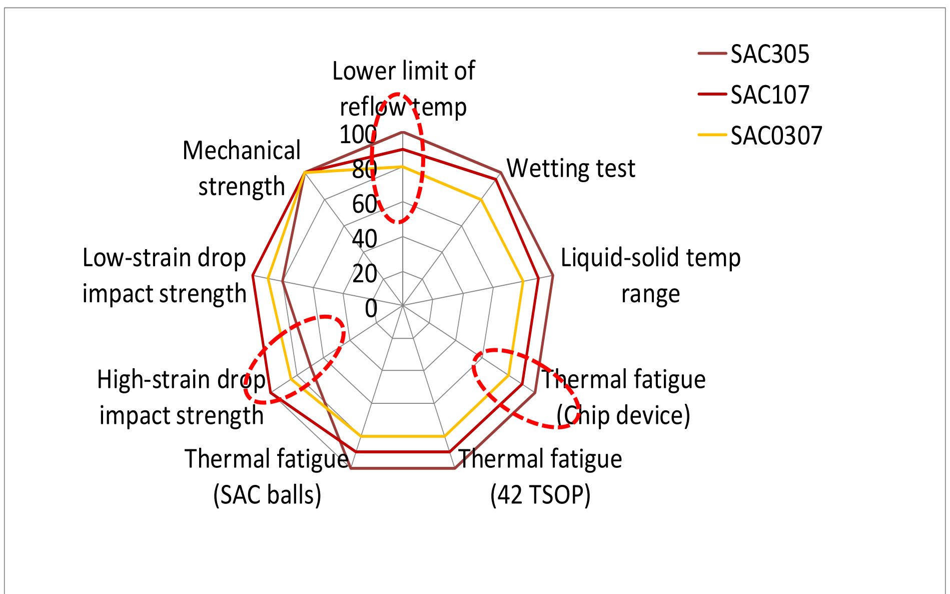
- **Sn-1.0Ag-0.7Cu**

Recommended as alternative alloy to SAC305

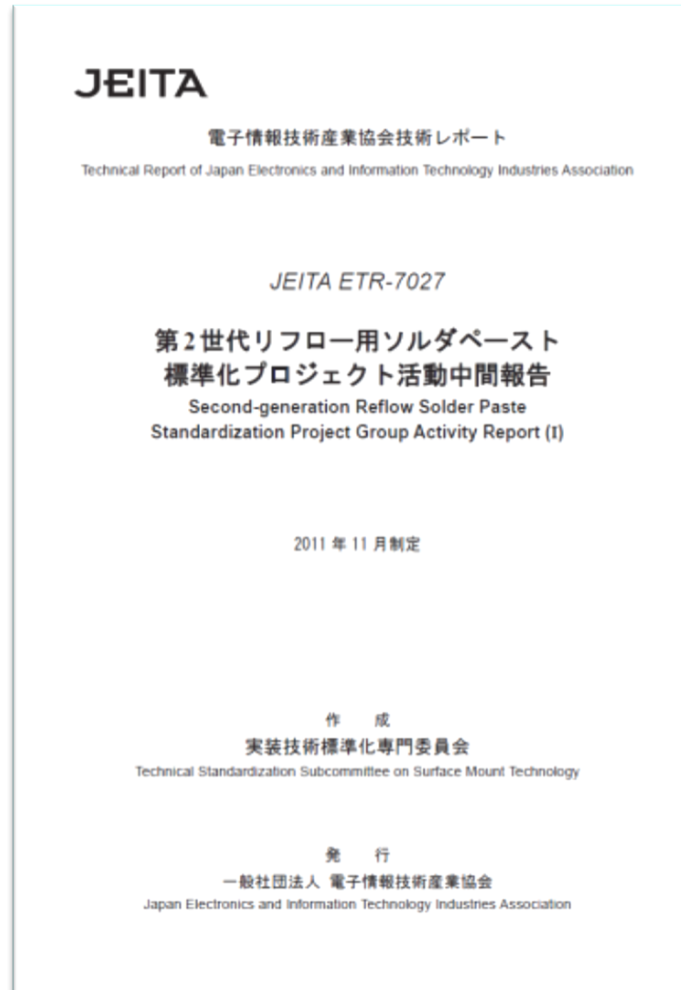
In addition,

- **Sn-0.3Ag-0.7Cu**

Recommended under limited conditions due to constraint in peak reflow temperature



Difference in properties between SAC305 and low-Ag



JEITA

電子情報技術産業協会技術レポート

Technical Report of Japan Electronics and Information Technology Industries Association

JEITA ETR-7027

第2世代リフロー用ソルダペースト
標準化プロジェクト活動中間報告

Second-generation Reflow Solder Paste
Standardization Project Group Activity Report (I)

2011年11月制定

作　成
実装技術標準化専門委員会
Technical Standardization Subcommittee on Surface Mount Technology

発　行
一般社団法人 電子情報技術産業協会
Japan Electronics and Information Technology Industries Association

Project Action Plans

1. Obtain suggestions from the solder manufactures

Low-Ag SAC Paste

- Increase in reflow temp
- Impact on thermal fatigue and wetting

→

- **Lower temp by adding Bi in 1Ag & 0.3Ag base SAC**
- **Improve properties by adding trace elements**

Sn-Bi low-temp Paste

- Impact on shock strength
- Creep fatigue & max operating temp

→

- **Sn-58Bi & Sn-57Bi-1Ag properties behavior cannot be determined**
- **No improvement on high-strain impact strength. High potential, but suspended for general use**

Specialized Paste

- Effectiveness of additives
- Side effects

→

- **Research market demand**
- **Unable to narrow down. May need to be customized by application. No progress**

2. Quantification of properties using use-friendly methods → **<u>Challenge towards new test methods</u>**

3. Licensing terms for alloy candidates are RAND basis → **<u>Agreed upon at the start of project</u>**

2nd Gen Solder Alloy Recommended by JEITA PG

Sn- 1Ag- 0.7Cu- 2Bi*

Why?

1. Compatible with SAC305 reflow profile
2. Similar mechanical properties and impact strength as SAC305

However,

1. High-strain thermal fatigue properties are lower than SA305
2. Stress can not be applied during cooling due to a gap between solidus & liquidus temp

Phase 2 Evaluation: Alloys & Test Parameters

- ❑ **Direction of 2nd phase eval**

Low-Ag SAC

Reflow Temp

(1) Verification of effect on lower reflow temp (Bi & In)

- ☐ **Lower limit temp check**
- ☐ **Profile Wetting Test**

Bi: 0～3%
In: 0～0.5%
Determined based on the preliminary study of SAC+Bi

(2) Identification & Quantification of deteriorated properties

- ☐ **Izod Test**
- ☐ **HS Test**
- ☐ **TSOP Peel Strength**
- ☐ **Ball Shear**

○ Sn-0.3Ag-0.7Cu + Bi + α
○ Sn-1.0Ag-0.7Cu + Bi + α

(3) Improvement of deteriorated properties

- ☐ **Effects of elemental dopants**

Required Properties

◎ SAC305

	SAC & SnBi	SAC0.3 & SAC1.0	SN58B1 & 57Bi1Ag	Standard & Heat limit
Chip shear test	○	×	×	×
High-speed shear test	○	○	—	×
Impact bending test	○	○	×	×
Limit bending test	○	×	×	×
Thermal shock and fatigue test	○	○	○	×
Meniscograph test	○	○	×	—
Spreading test	○	○	○	—

Phase 2 Evaluation Solder Candidates

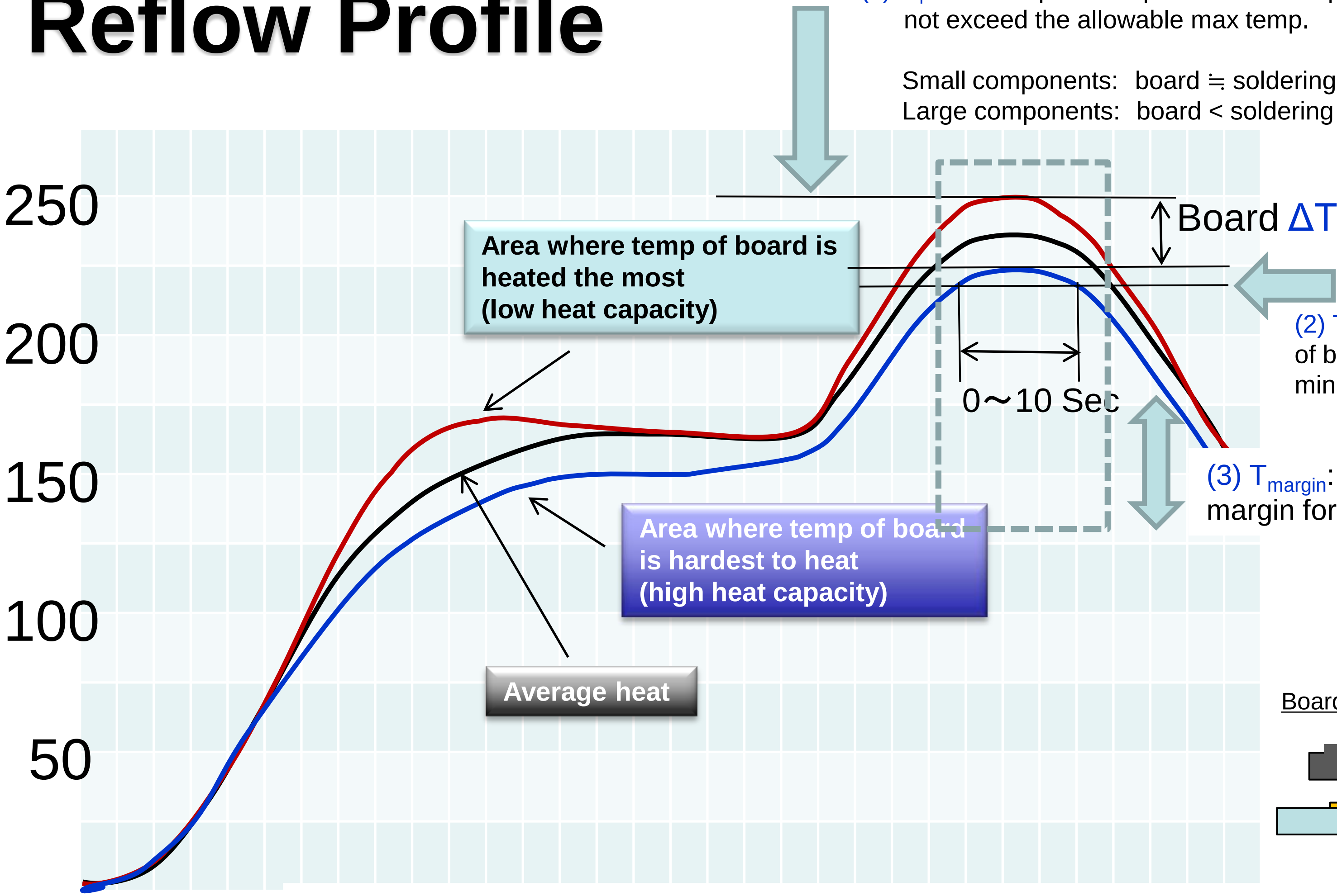
No.	Sn	Ag	Cu	Bi	In	Others	Remarks
1	Bal	3	0.5				Ref: SAC305
2	Bal	1	0.7	1.6	0.2		(Senju alloy code: M40)
3	Bal	1	0.7				Evaluate the effects of Bi-doped SAC107
4	Bal	1	0.7	2			
5	Bal	1	0.7	3			
6	Bal	1	0.7	1			Evaluate the effects of In-doped SAC107+1Bi
7	Bal	1	0.7	1	0.2		
8	Bal	0.3	0.7	3			Evaluate the effects of In-doped SAC0307+3Bi
9	Bal	0.3	0.7	3	0.2		
10	Bal	1	0.5	3		Ni 50ppm	Evaluate the effects of Ni-doped SAC107+3Bi
11	Bal	1	0.7	1.5	0.2	+α	(Harima Chemicals codes: LS1.0A1, LS1.0A2) Evaluate the effects of Sb addition and In increase
12	Bal	1	0.7	1.5	0.5	0.5Sb+β	

Melting Point & Reflow Temperature

Reflow Profile

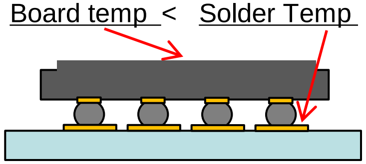
(1) T_P : Set the peak temp so that all components on the board must not exceed the allowable max temp.

Small components: board ≒ soldering location ≒ board temp
Large components: board < soldering location



(2) T_{min} : Entire soldering temp of board must meet sufficient min temp (Above X℃ & Y sec)

(3) T_{margin}: Must consider temp margin for production line (min 5℃)



(Ex.) T_{min} : T_P260℃ − ΔT20℃ − T_{margin}5℃ = 235℃

T_P245℃ − ΔT15℃ − T_{margin}5℃ = 225℃

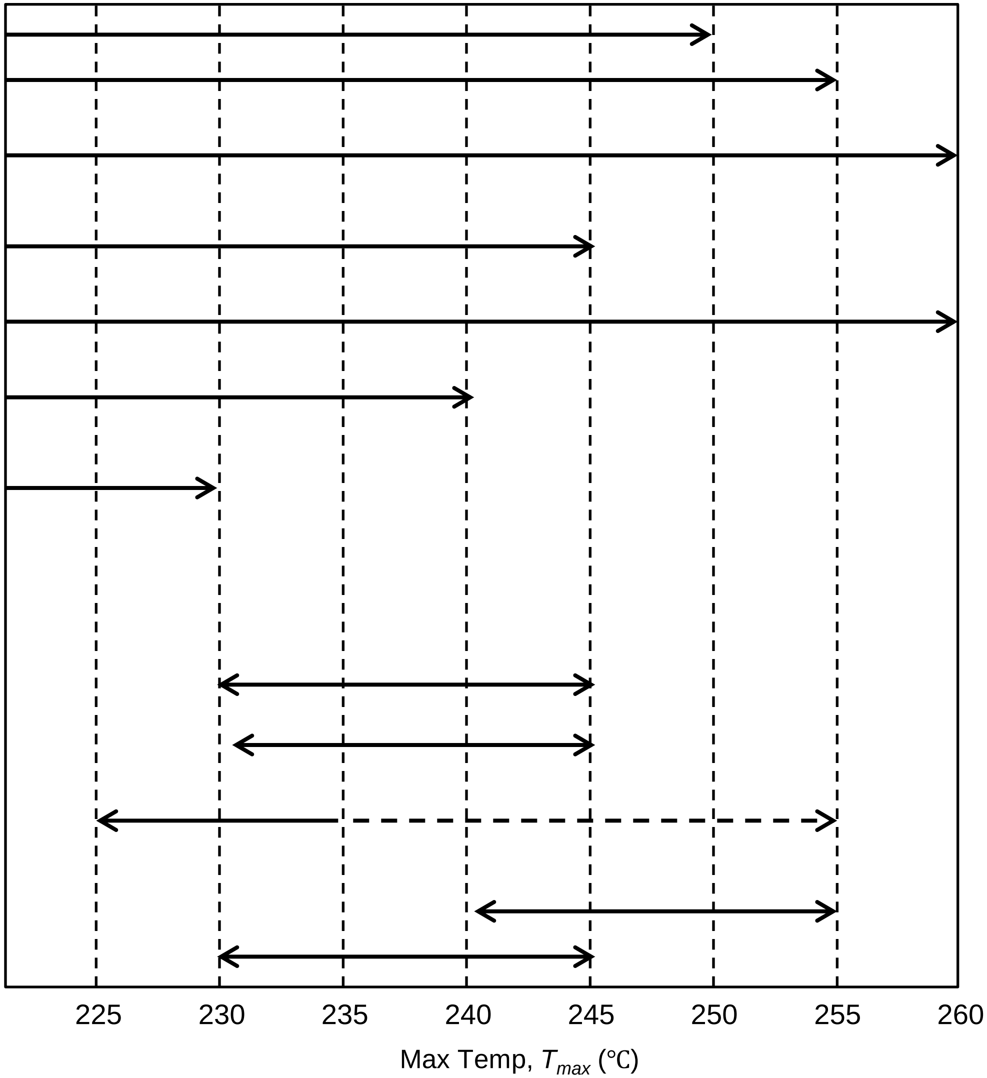
Reflow Temp Requirements

Reflow heat resistance of components

Parts/Standards	Temp x Time, T_{max}	Max, T_{max}
JIS C60068-2-58	220℃ X 60～90s	250℃
JIS C60068-2-58	220℃ X ≦60s	255℃
IPC/JEDEC J-STD 020D small & thin	217℃ X 60～150s	260℃
IPC/JEDEC J-STD 020D large & thick	217℃ X 60～150s	245℃
Semiconductor company "T"	230℃ X 30～50s	260℃
Al electrolytic capacitor（medium)	220℃ X ≦30s	240℃
Al electrolytic capacitor（large)	217℃ X ≦20s	230℃

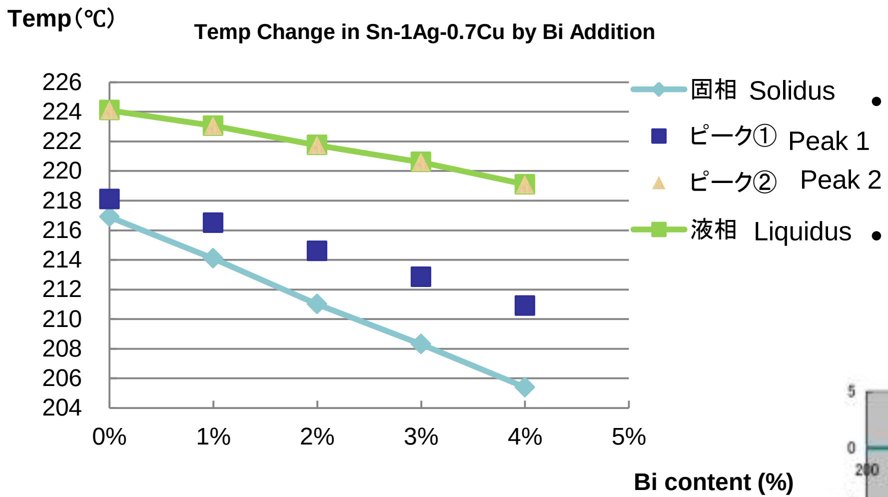
Solder reflow temp used by assembly manufacturers

Mfr	Min, T_{min}	Max, T_{max}	Diff, ΔT
S	230℃	245℃	15℃
P	232℃	245℃	13℃
T	Solder liquidus +(5~10℃)	Component heat resistance -(5~10℃)	-
A	240℃	255℃	15℃
F	230℃	245℃	15℃

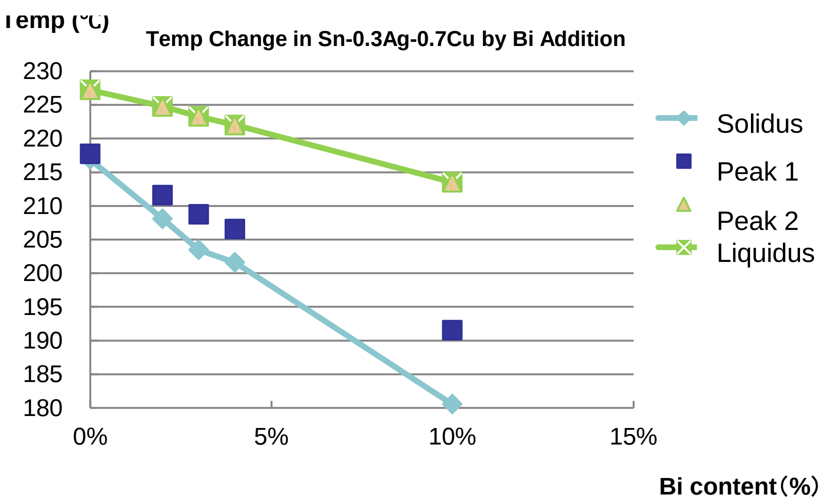


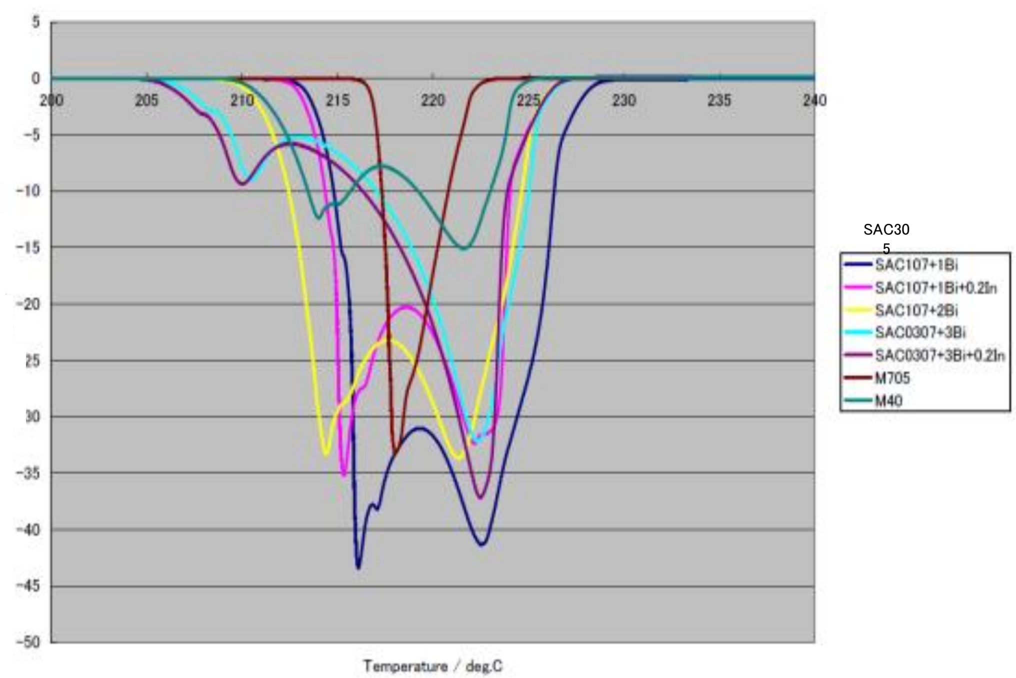
Melting & Wetting Test

The Effect of Bi on Melting Temp

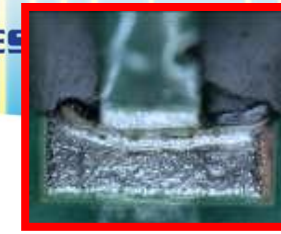


- When 1% Bi is added to 1Ag alloy, solidus and liquidus temp will drop 3ºC and 1ºC respectively.
- When 1% Bi is added to 0.3Ag alloy, solidus and liquidus will drop 3.6ºC and 1.3ºC respectively.





Lower Limit Temp in Reflow

○：Fillet formed　　×：Fillet not formed

【Conditions】

Equipment：Reflow simulator (Sanyo Seiko SP-5000DS)

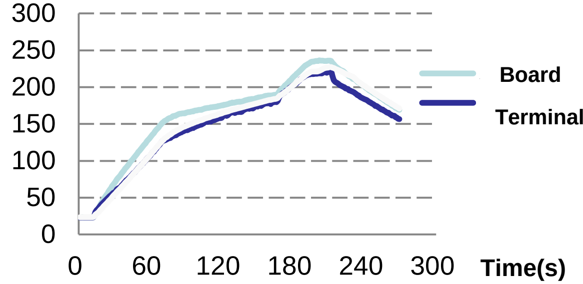
Component : 8mm dia. coil
Board size　:　30mm x 30mm
Component location　: Center
Soldering Method : Screen print

【Method】

After heating with reflow simulator, verify fillet formation on the 8mm coil

【Temp Profile】

Example: 225℃ or higher for 10s



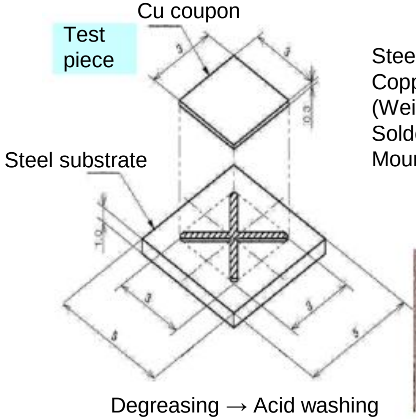
Against lower limit (230ºC) reflow profile:

SAC305	: more than 5ºC margin
107+2~3Bi	: 5℃ margin ensured
(M40)	: 5℃ margin ensured
SAC107+1Bi	: Margin decreased to 3ºC
SAC107	: No margin

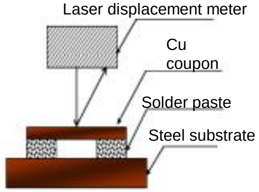
Actual measurement (others are estimate)

Solder Composition					Solidus (℃)	Liquidus (℃)	Delta (℃)	Reflow Temp(℃) (Hold for 10 sec)										
Sn	Ag	Cu	Bi	In				220	221	222	223	224	225	226	227	228	229	230
Bal	3	0.5			217	218	1	×			○	○	○	○	○	○	○	○
Bal	1	0.7	1.6	0.2	210	222	12	×	×	×	×		○	○	○	○	○	○
Bal	1	0.7			217	224	7	×	×	×	×	×	×	×	×			○
Bal	1	0.7	1		214	223	9	×	×	×	×	×	×		○	○	○	○
Bal	1	0.7	1	0.2	213	223	10	×	×	×	×	×	×		○	○	○	○
Bal	1	0.7	2		211	222	11	×	×	×	×		○	○	○	○	○	○
Bal	1	0.7	3		208	221	13	×	×	×	×		○	○	○	○	○	○
Bal	0.3	0.7	3		203	223	20	×	×	×	×	×	×		○	○	○	○
Bal	0.3	0.7	3	0.2	206	223	17	×	×	×	×	×	×		○	○	○	○

Wetting Test

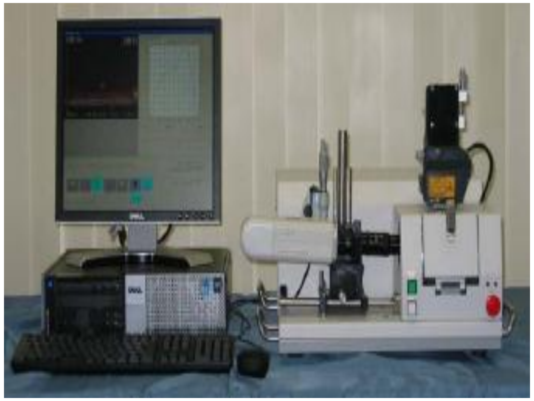


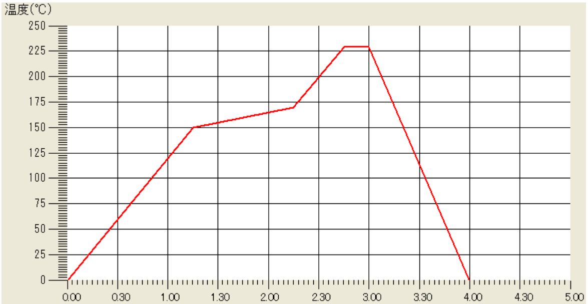
Steel substrate: 5 mm-square, t=1.0 mm
Copper piece: 3 mm-square, t=0.3 mm
(Weight: 24 mg)
Solder paste print thickness: 120±10 μm
Mount height of copper piece: 90±10 μm



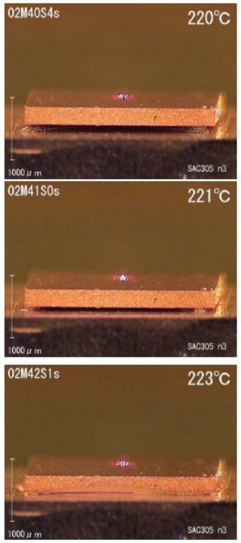
Displacement wetting test by profile heating

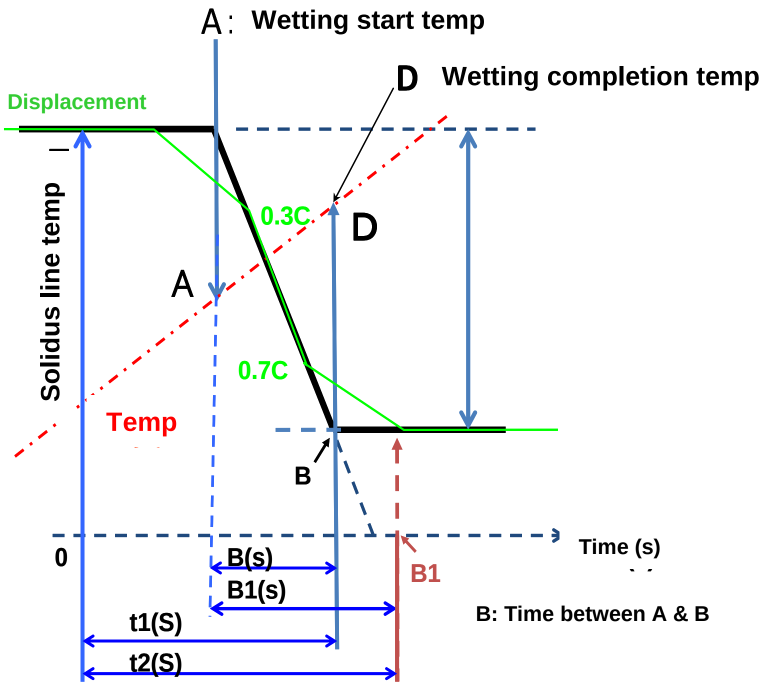
- Possible to compare wetting values using Cu coupon
- Possible to measure the temp & time at the start and the completion of wetting



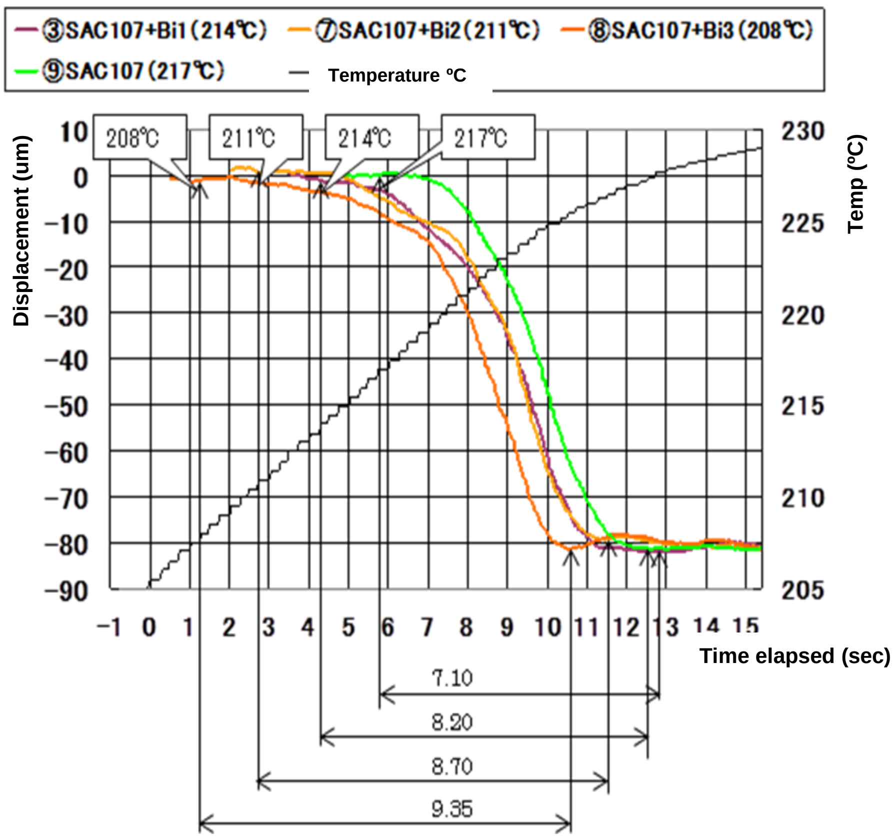


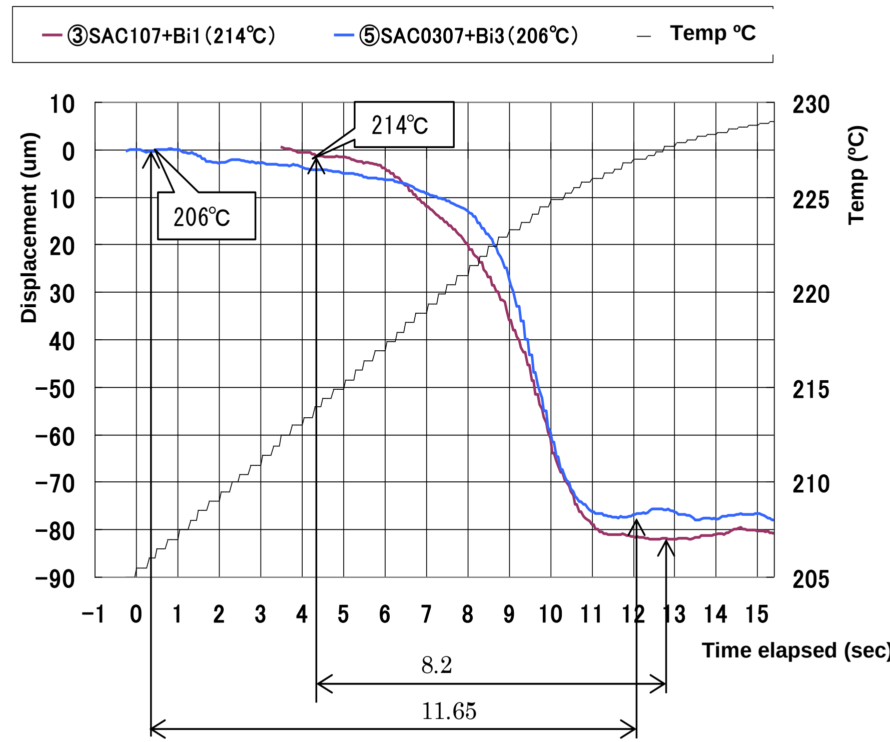
STEP	1	2	3	4	5	6
時間(分.秒)	0.00	1.15	1.00	0.30	0.15	1.00
温度(℃)	0	150	170	230	230	0
勾配(℃/sec)	0	2	0.3	2	0	-3.8





Wetting Test Results





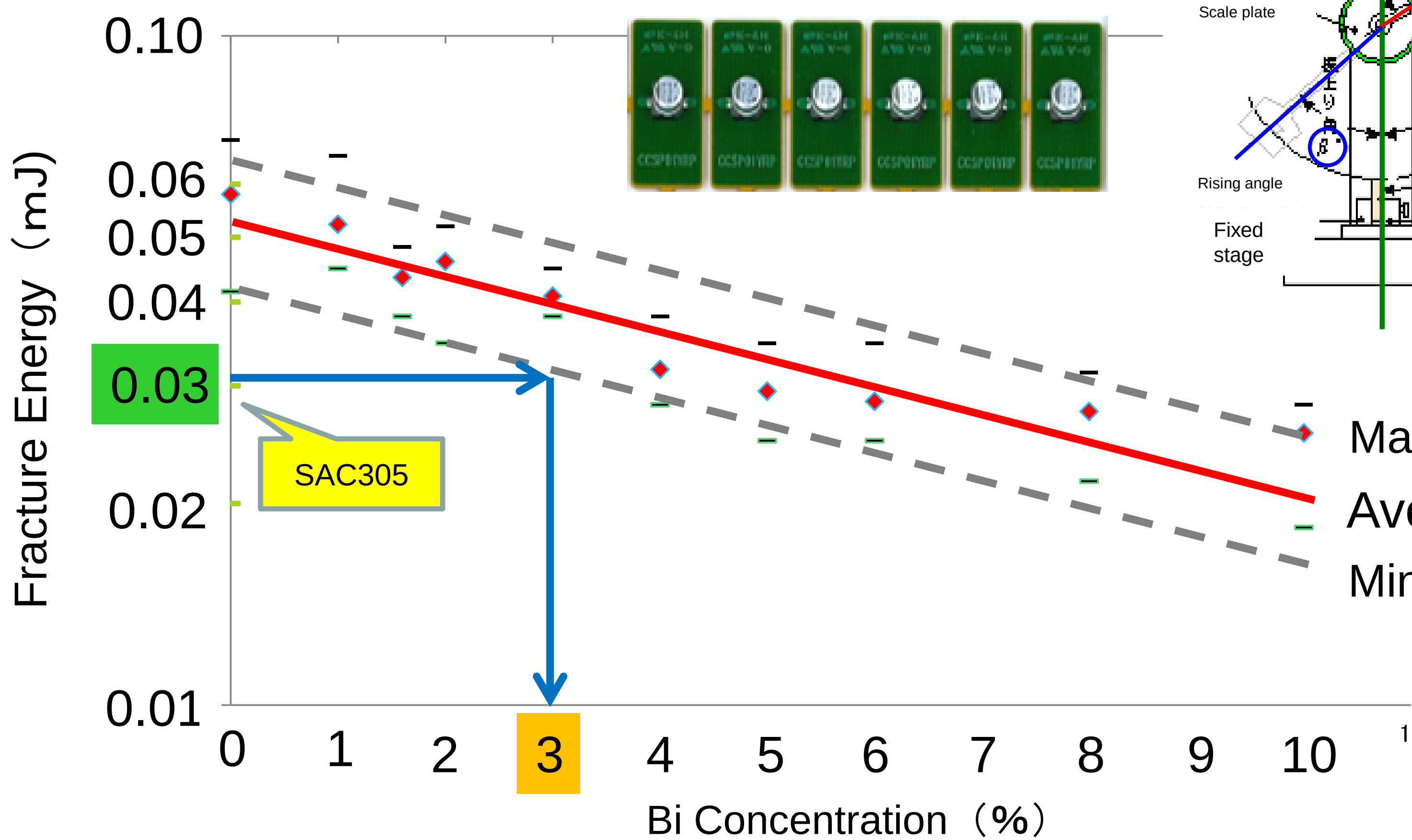
	Composition	Solidus (ºC)	Liquidus (ºC)	t2 (sec)	Wetting time
③	SAC107+Bi1	214	223	8.20	2:45.7
⑦	SAC107+Bi2	211	221	8.70	2:44.0
⑧	SAC107+Bi3	208	221	9.35	2:43.7
⑨	SAC107	217	224	7.10	2:46.1

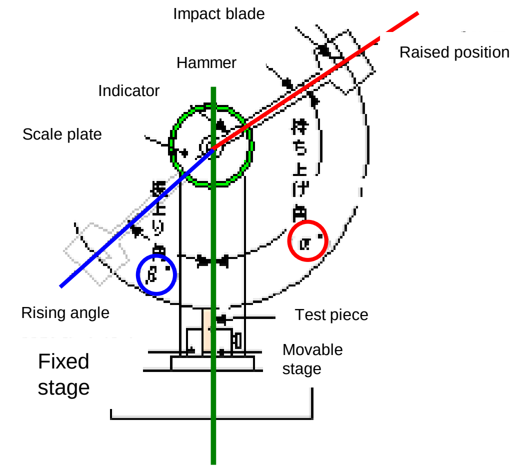
	Composition	Solidus (ºC)	Liquidus (ºC)	t2 (sec)
③	SAC107+Bi1	214	223	8.20
⑤	SAC0307+Bi3	206	222	11.65

Mechanical Strength Test

The Effect of Bi using Izod Impact Test

Component： Dia. 5mm Cap Aluminum (Nichicon UWT1C220MCR1GB)
Solder Paste： SAC (Ag0.3, Ag1.0, Ag3.0 wt%)

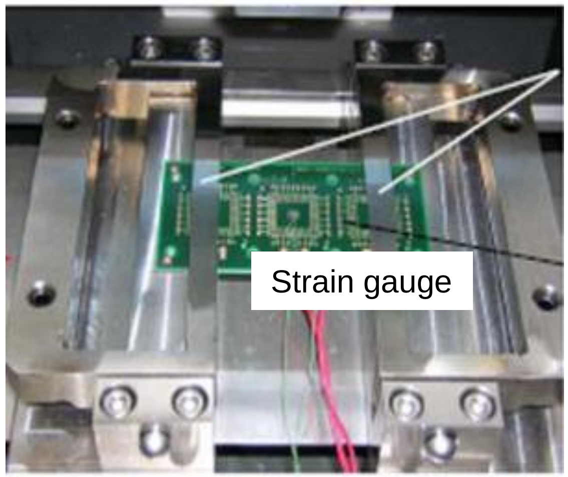


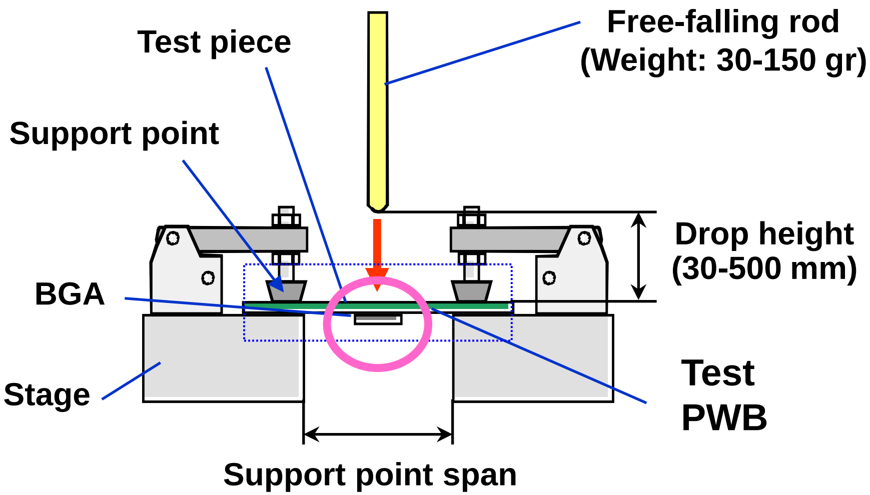


To meet SAC305 level, Bi content in SACB107 α must be 3wt% Max

Substrate Bending Test (Rod Drop)

(ED-4702B)
Rod Drop Impact Test：Impact Bending Test (IBT)

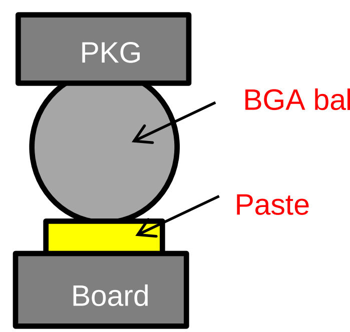




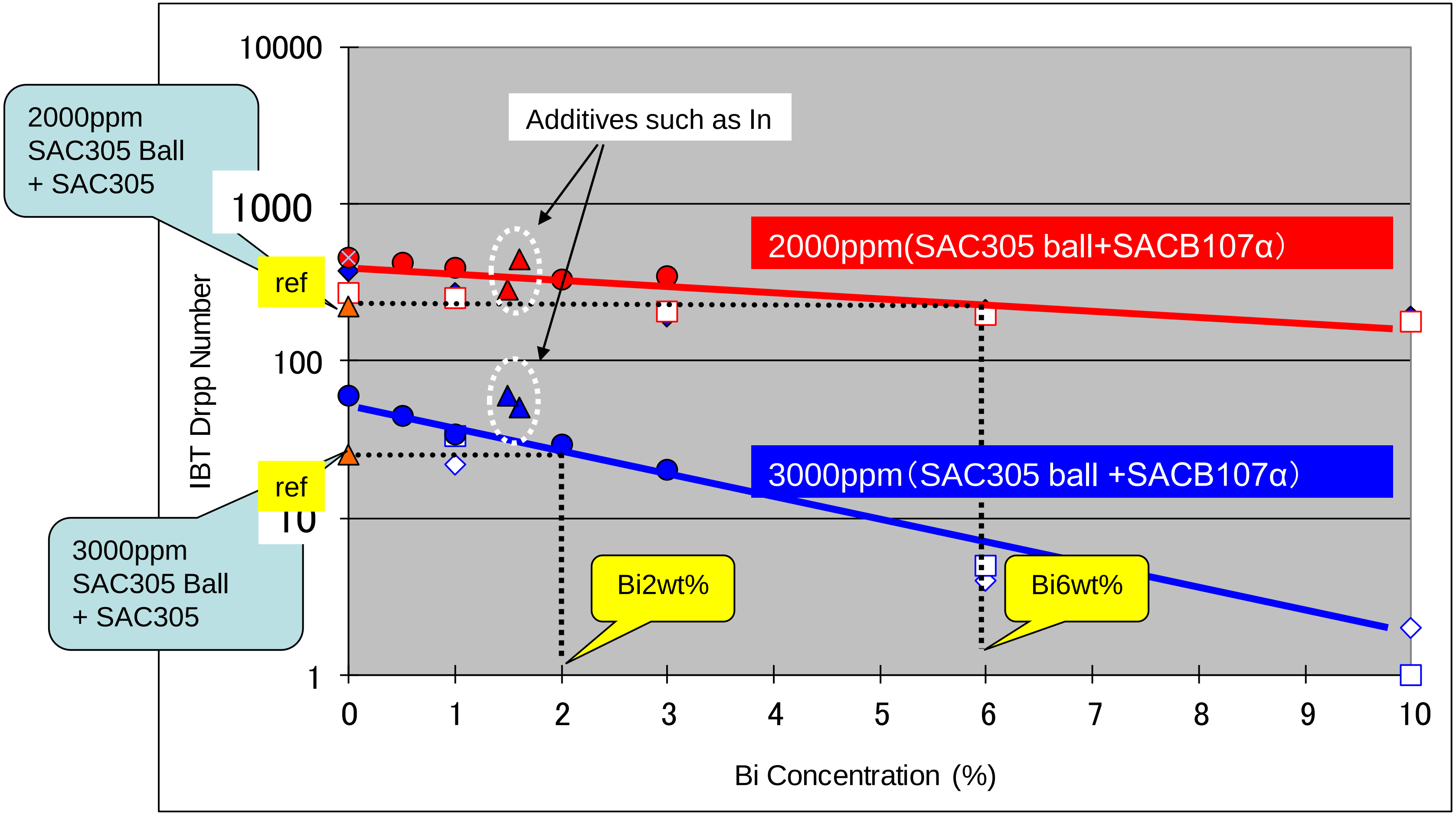
<Board>
Material：FR4
Pad：Cu-OSP
Outline：30x120x1.6mmt

<Sample>
BGA：1313-224 pins(0.5mP)
PKG pad：Electrolytic Ni/Au
Ball alloy: SAC305 &SAC105
Ball dia：0.3mm

<Reflow Profile>
Peak 235℃



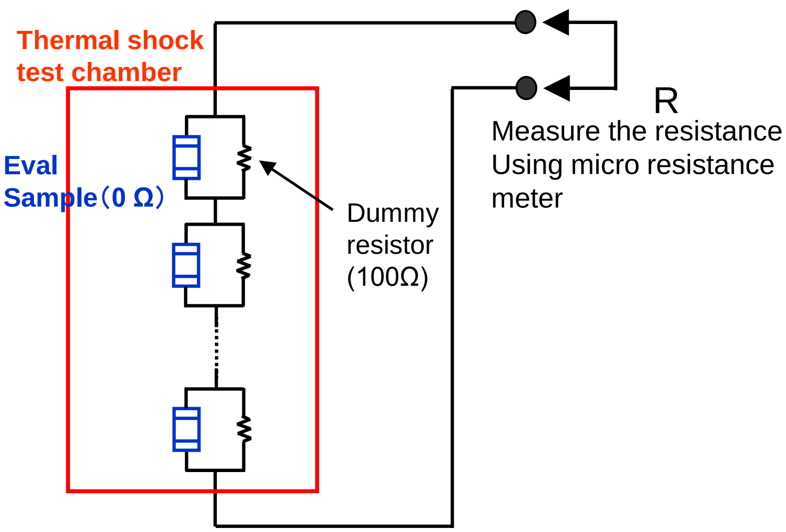
IBT Evaluation Results

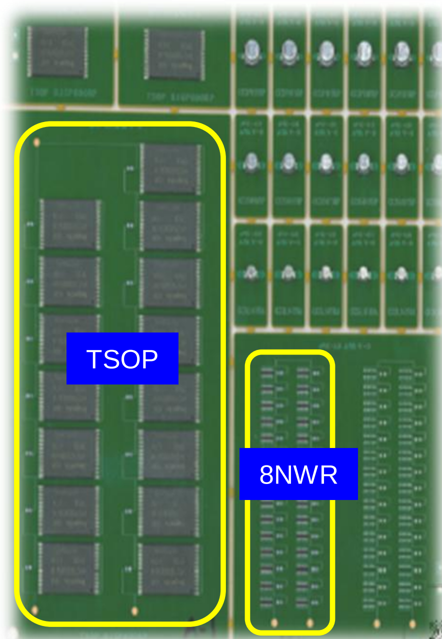


(1) For SAC305 ball & SACB107 paste combination, SAC305 equivalent level can be met when Bi is 6% for IBT (2000ppm) and 2% for IBT(3000ppm).
(2) For high-impact IBT (3000ppm), additives such as In are found to be effective.

Thermal Fatigue Test

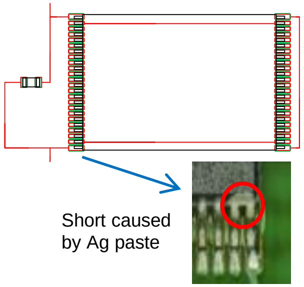
Overview of Thermal Fatigue Test





Components:
(1) Eight-ganged network resistor (8NWR)

(2) TSOP



Board : FR-4
Size : 160 x16mm
Thickness : 1.6mm
Screen thickness : 120μm

Test Conditions:
-25℃ ~125℃ (20min/cyc)　1500 cycle

Connect evaluation sample & dummy resistor (1608 size 100Ω) in parallel, then connect n=30 in series

⬇

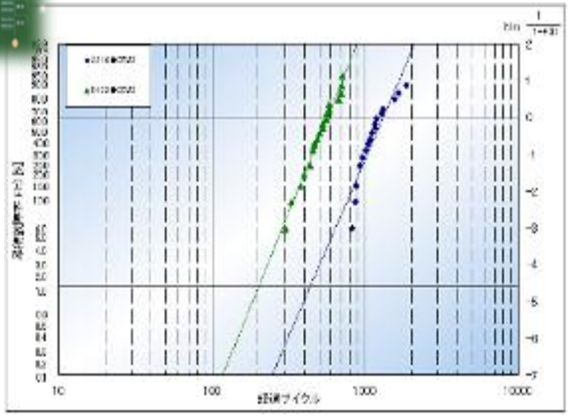
If open is found in one sample, detect the 100Ω of dummy resistor

⬇

By using micro meter, detect the change in resistance and determine the cycle where cracks had occurred (electrical opens)

⬇

Perform Weibull analysis and compute the cycle numbers at 1% cumulative failure rate

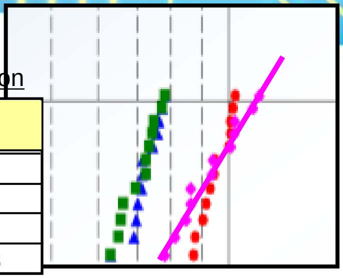


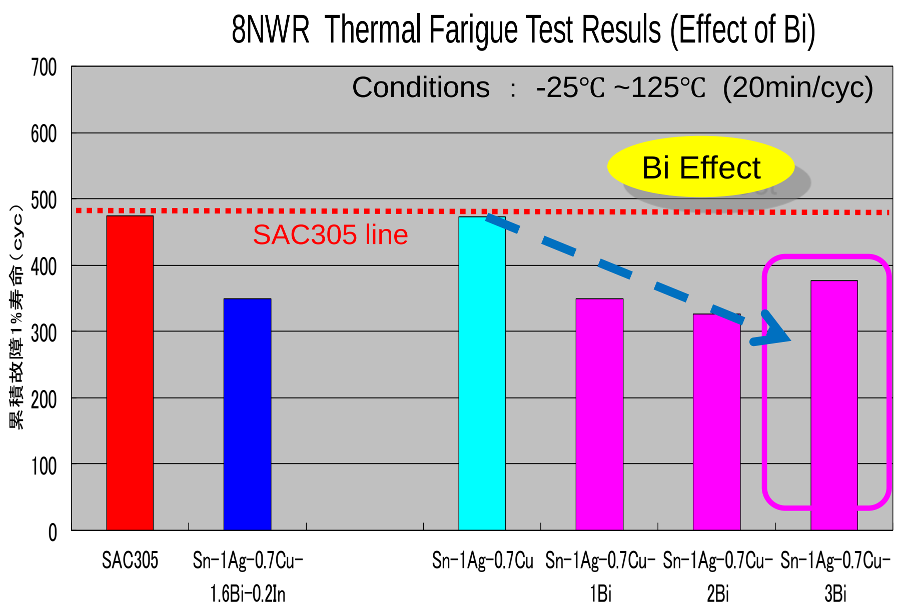
Test result example

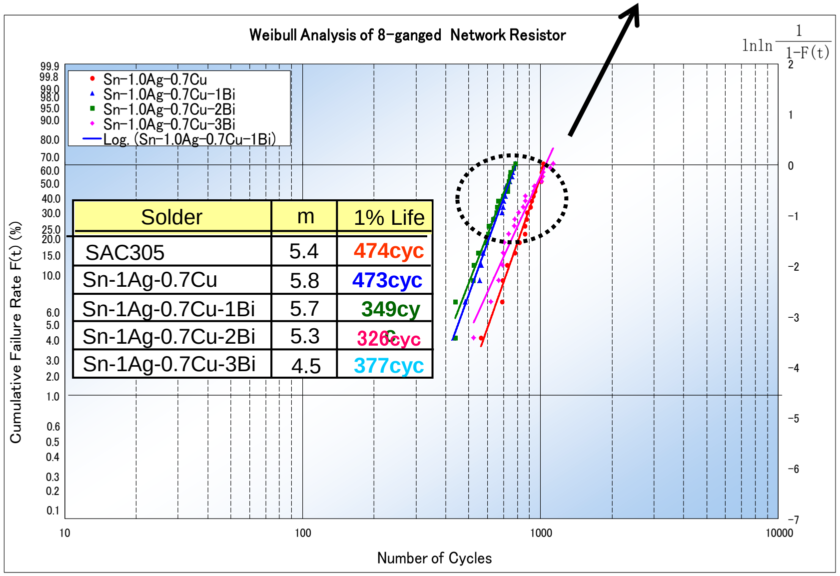
Thermal Fatigue Test Results (8NWR)

m values in the failure region

Solder	m
Sn-1Ag-0.7Cu	5.8
Sn-1Ag-0.7Cu-1Bi	6.5
Sn-1Ag-0.7Cu-2Bi	4.8
Sn-1Ag-0.7Cu-3Bi	2.8







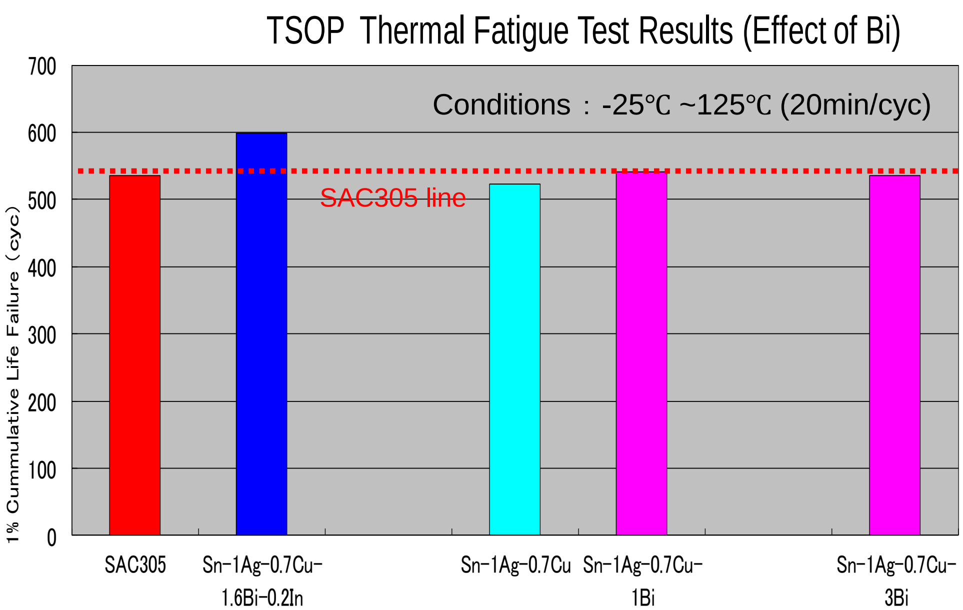
Solder	m	1% Life
SAC305	5.4	474cyc
Sn-1Ag-0.7Cu	5.8	473cyc
Sn-1Ag-0.7Cu-1Bi	5.7	349cy
Sn-1Ag-0.7Cu-2Bi	5.3	326cyc
Sn-1Ag-0.7Cu-3Bi	4.5	377cyc

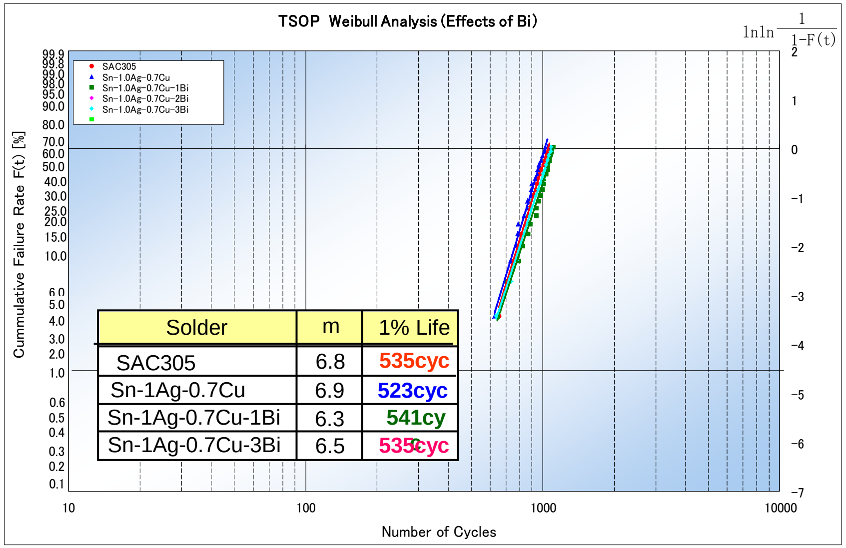
- Thermal fatigue life of Sn-1Ag-0.7Cu is similar* to that of SAC305
- The life of Sn-1Ag-0.7Cu drops by 20~30% when 1~3% of Bi is added.

※ As compared to Bi1% & Bi2%, the Weibull slope of Bi3% is different and therefore the failure mode is likely to be different

*Definition of “similar” : Nearly the same Weibull slope & cycle # at 1% cumulative failure rate is within ±10%

Thermal Fatigue Test Results (TSOP)





- Thermal fatigue life of Sn-1Ag-0.7Cu is similar to that of SAC305
- Life of Sn-1Ag-0.7Cu similar when 1% & 3% Bi are added

  ⇒ Same results as previous small quantity testing

- Slight increase in life for Sn-1Ag-0.7Cu-1.6Bi-0.2In as compared to SAC305 (by 10%)

Previous test results Conditions: -40℃ ~125℃ (60min/cyc)

Base Solder	B content (%)	200cyc	400cyc	600cyc
Sn-1Ag-0.7Cu	0	0/3 NG	0/3 NG	2/3 NG
	3	0/5 NG	0/5 NG	1/5 NG
	5	0/5 NG	3/5 NG	**5/5 NG**
	8	0/5 NG	4/5 NG	**5/5 NG**
	10	0/5 NG	**5/5 NG**	**5/5 NG**

Dramatic drop in life when Bi is added by 5% or more

Summary & Conclusion

Selection of low-Ag SAC alloy

Based on the Phase 2 evaluation results, Sn-1Ag-0.7Cu-2Bi is the recommended alloy for the low-Ag alternative.

Both Sn-0.3Ag-0.7Cu & Sn-1.0Ag-0.7Cu are potential candidates for the alternative alloy. However, the lowest allowable heating temp is the major weakness of these alloys. According to the test results, when the peak temp is set at 230℃ the following can be summarized against the melting temp limit.

1. The current SAC305 has a margin of 5℃＋α
2. SAC107 has no margin at the lower limit
3. SAC107 + 2%Bi ensures a margin of 5℃

Low-temp and specialized alloys

This project has been suspended because industry-wide standard alloy cannot be identified. We look forward to the developmental activities by others.