Difference Between Various Sn/Ag/Cu Solder Compositions

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About Nihon Almit Co., Ltd.

- Founded: 1956

- Leading manufacturer in Japan for solder products.
- First manufacturer in the world to produce aluminum solder.
- SnPb products adopted and used by NASA for space shuttle project.

- Customers:

Automotive: Honda / Hyundai / Mitsubishi / Nissan / Toyota / Volvo

Non-Automotive: Ericsson / Hitachi / LG / NEC / Panasonic / Philips / Pioneer / Samsung / Sanyo / Sharp / Siemens / Sony

1.1 Overview

The use of lead is being banned to help preserve the environment, and the traditionally used Sn-Pb solder is being restricted (RoHS etc.)
From reliability standpoints, Sn/Ag/Cu alloys has been chosen as the replacement for Sn-Pb solder.
However, there is no industry standard on which alloy to chose among the various Sn/Ag/Cu alloys available in the market.

- Sn + 3.9% Ag + 0.6% Cu (iNEMI recommended)
- Sn + 3.5% Ag + 0.7% Cu
- Sn + 3.0% Ag + 0.5% Cu (JEITA recommended)

Purpose of this test
- To determine the difference in performance and reliability among the various Sn/Ag/Cu alloys, and find out which alloy will be best suited for various applications, especially under harsh environmental conditions.

1.2 Lead-free Progress for Automotive

2005-2006: Continue evaluation

2005: Start use for new designs

2006: Start low volume production

2008: Start mass-production / eliminate SnPb solder

Note: The above information is a summary of various manufacturer's schedules. Actual schedule and procedures will vary by company.

2. Evaluation Points

1) Tensile Strength / Elongation / Yield Point
2) Young’s Modulus / Poisson’s Ratio
3) Thermal Conductivity (at 60 °C) / Specific Gravity
4) Specific Heat
5) Coefficient of Thermal Expansion / Thermal Expansion ratio
6) Visual Appearance (Whitening phenomenon)

Note: number of samples tested (n) = 3 of each alloy for tests 1-5

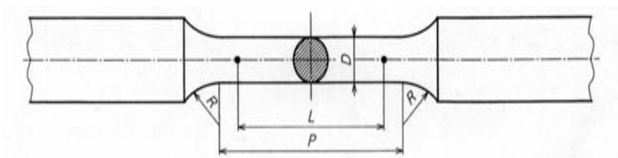
2. Test Samples

・Composition of test samples

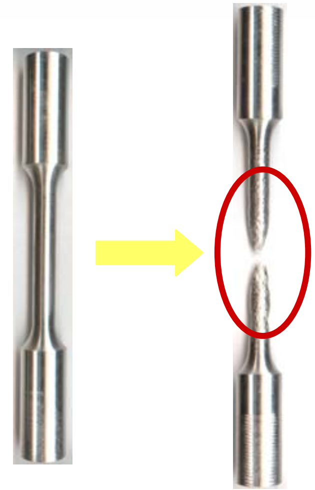
	Composition	Note
Sample 1	Sn-3.9Ag-0.6Cu (SAC396)	iNEMI recommended
Sample 2	Sn-3.5Ag-0.7Cu (SAC357)	
Sample 3	Sn-3.0Ag-0.5Cu (SAC305)	JEITA recommended
Reference	63Sn-37Pb	Eutectic Solder

2.1 Tensile Strength

Test Method: Tensile Strength Measurement eqp.
Test Specimen: Shown below

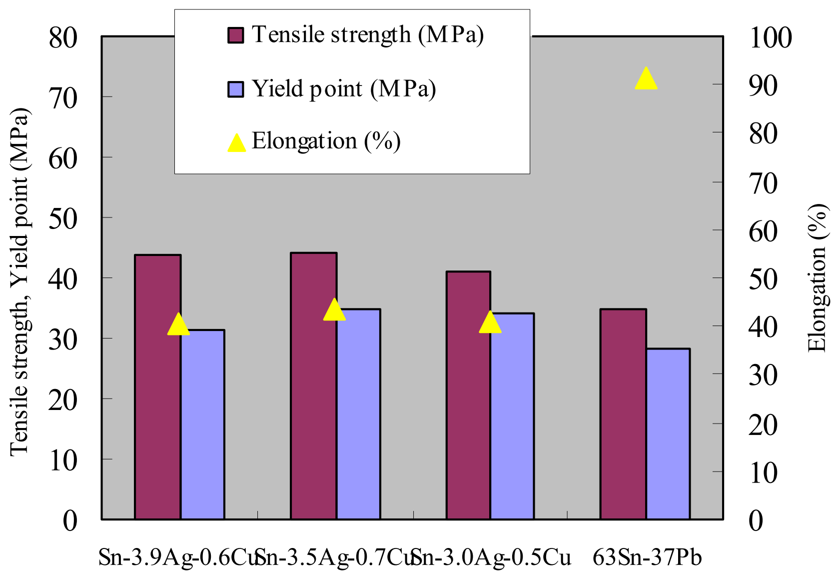


Diameter: 10mm
Length: 50mm
Parallel: 60mm
R: 15



Before **After**

Test environment: 25 °C
Pull Speed: 10mm/min

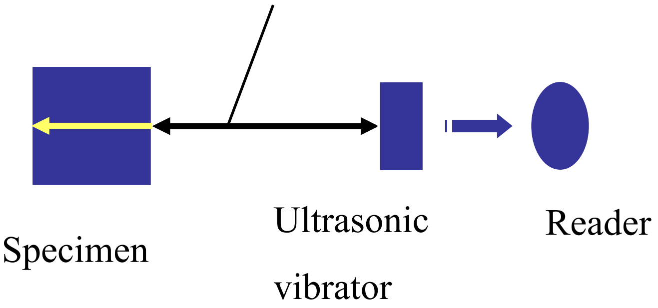


Test Equipment

(Shimadzu)

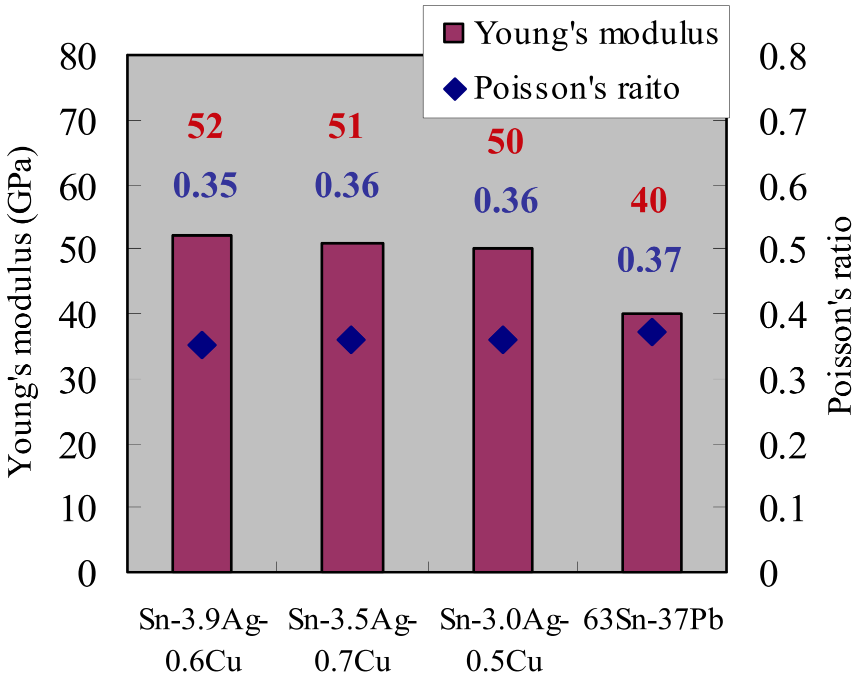
2.2 Young's Modulus / Poisson's Ratio

Test Method: Ultrasonic
ie) Calculate the Young's Modulus and Poisson's Ratio from the speed that the ultrasonics travel through the metal
Test Specimen: 20mm sq, t=10mm
Test Environment: 25 °C



Young's modulus = sonic speed x (density)^2

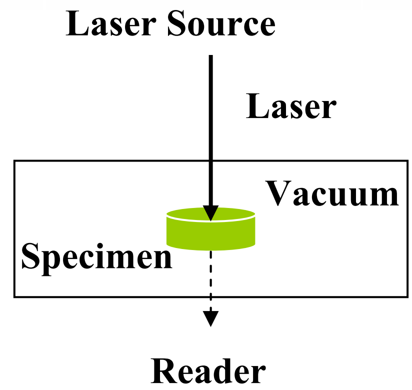
Results:



Ultrasonic measurement equipment (Matech)

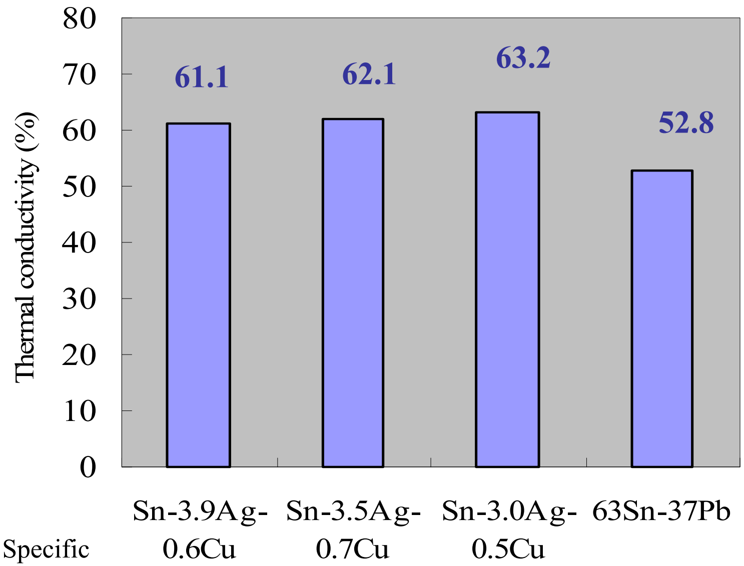
2.3 Thermal Conductivity / Specific Gravity

Test Method: Laser Flash Method
ie) Apply laser beam to test specimen, measure the calories and time from the back side, and calculate the specific gravity and thermal conductivity.



Test Specimen: 10mm diameter / t = 2mm
Test Environment: 25C / 60% RH / vacuum

Test Results



	Sn-3.9Ag-0.6Cu	Sn-3.5Ag-0.7Cu	Sn-3.0Ag-0.5Cu	63Sn-37Pb
Specific gravity	**7.4**	**7.4**	**7.4**	**8.4**

Thermal conductivity =

specific heat x heat diffusion x specific gravity

Thermal Conductivity Measurement eqp.

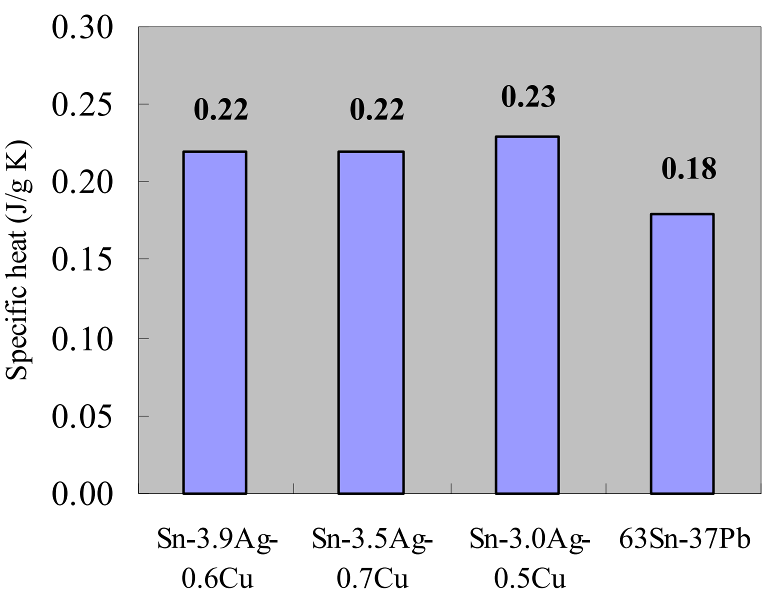
(Ulvac-Rico Inc.)

2.4 Specific Heat

Test Method: Insulating Continuous Method
ie) Measure the temp difference between the specimen and the insulated container, and calculate the specific heat

Test Specimen: 10mm dia x t=2mm
Test Environment: 25 C

Test Results:



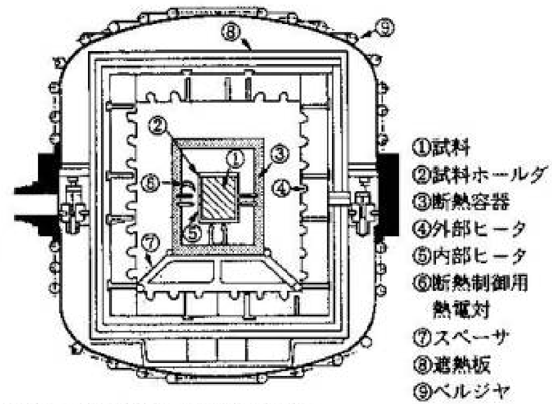


図1 SH-3000-M 型熱量計

Outline of test equipment

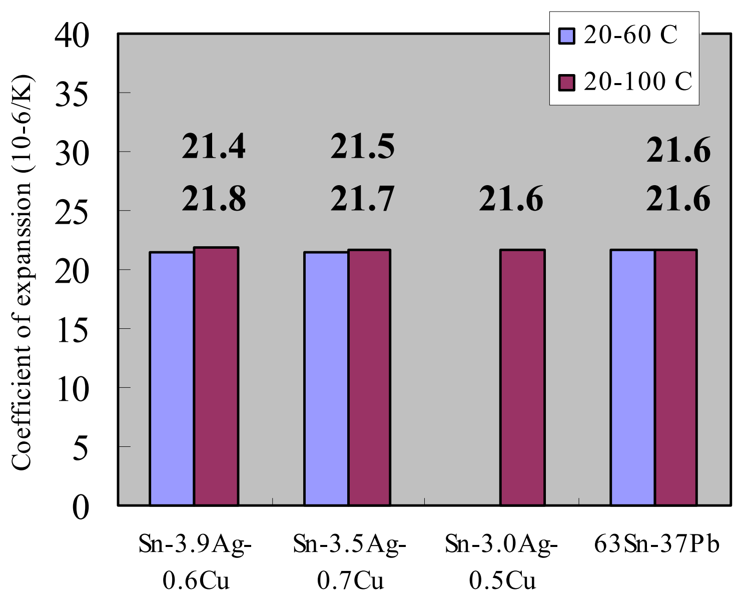
Test equipment (Ulvac-Rico)

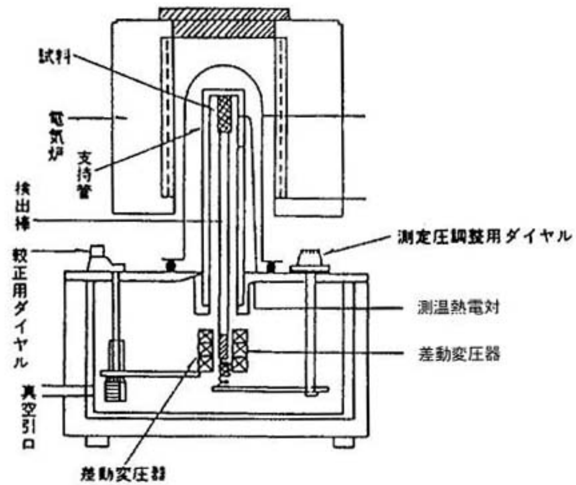
2.5 Coefficient of Thermal Expansion (CTE)

Test Method: Heat Expansion Measurement
ie) The metal expansion transferred from the measurement stick to the pressure reader will be transferred to voltage and recorded.

Test Specimen: 4mm × 4mm × t=10mm
Test Environment: 20-60°C / 20-100°C

Test Results:





Outline of equipment

(Alvac-Rico)

2.6 Test Results

Chart 2. Mechanical Properties Test Results (n=3)

		Sn-3.9Ag-0.6Cu	Sn-3.5Ag-0.7Cu	Sn-3.0Ag-0.5Cu	63Sn-37Pb
Liquidus Temp C		218	218	220	183
Solidus Temp C		217	217	217	183
Tensile Strength (MPa)		43.7	44.0	41.1	34.7
Yield Point (MPa)		31.3	35.0	34.2	28.4
Elongation (%)		40.6	43.4	41.0	91.2
Coefficient of Work Hardening		0.083	0.056	0.040	0.032
Young's Modulus (GPa)		52	51	50	40
Poisson's Ratio		0.35	0.36	0.36	0.37
Specific Gravity		7.4	7.4	7.4	8.4
Specific Heat (J/g K)		0.22	0.22	0.23	0.18
Thermal Conductivity (%) 25C		61.1	62.1	63.2	52.8
Thermal Conductivity (%) 60C		0.085	0.086	---	0.086
Thermal Conductivity (%) 100C		0.174	0.173	0.173	0.173
CTE (10^{-6}/K)	20-60C	21.4	21.5	---	21.6
	20-100C	21.8	21.7	21.6	21.6

2.7 Observations

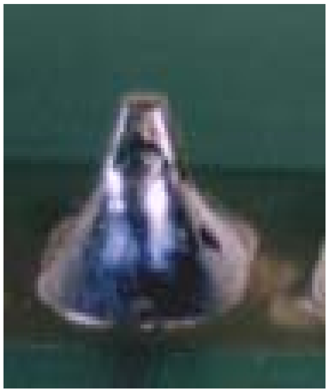
- The 3 various SAC alloys perform similarly with only a nominal variation level, and there seems to be no difference among the various alloy's mechanical properties.

Ref. SAC vs. Sn63

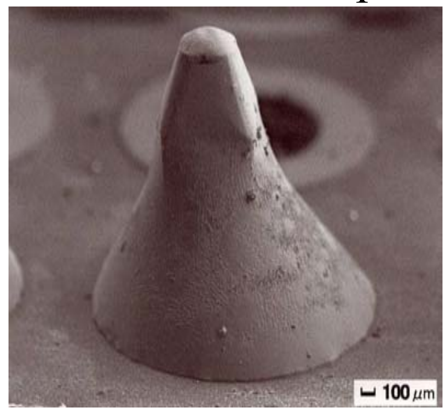
	SAC	Sn63
Tensile Strength	O	
Yield Point	O	
Elongation		O
Young's Modulus	O	
Poisson's Ratio	O	O
Specific Heat	O	
Thermal Conductivity	O	
CTE	O	O

2.8.1 Visual Appearance and Whitening Phenomenon

63Sn-37Pb

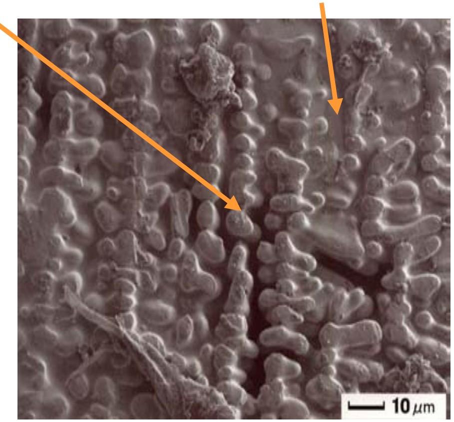


Sn-3.5Ag-0.7Cu



Beta Sn forming peaks

Sn-Ag-Cu forming valleys



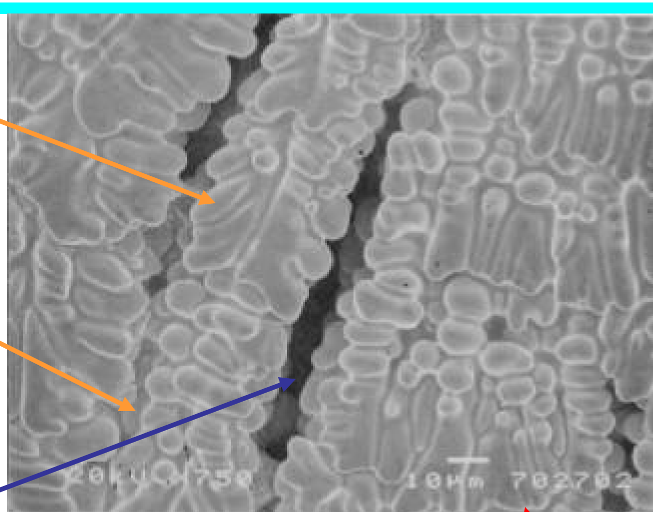
Whitening phenomenon occurs when Beta Sn forms peaks and Sn-Ag-Cu forms valleys in the SAC alloys.
Deep valleys may cause Hot-Tear, which is different from cracking.

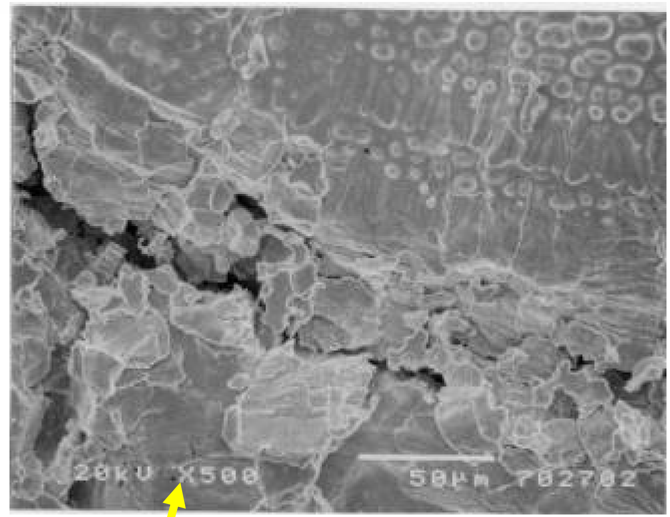
2.8.2 Difference between “Hot-tear” and “Crack”

Beta Sn

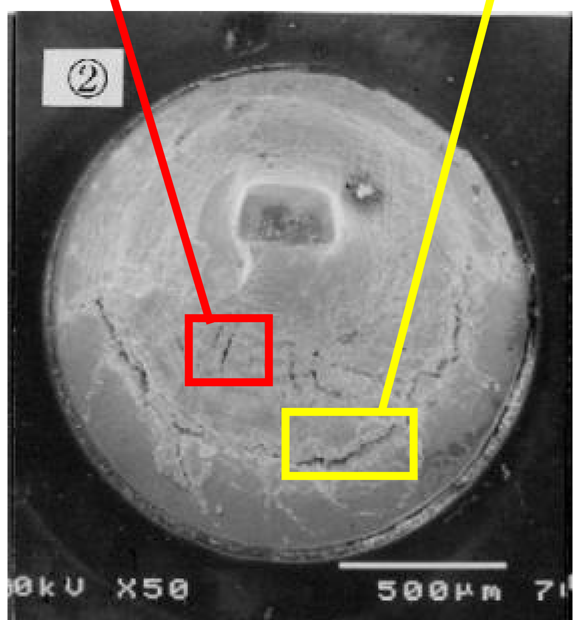
Sn-Ag-Cu

Deep Valley = **Hot Tear**





Crack

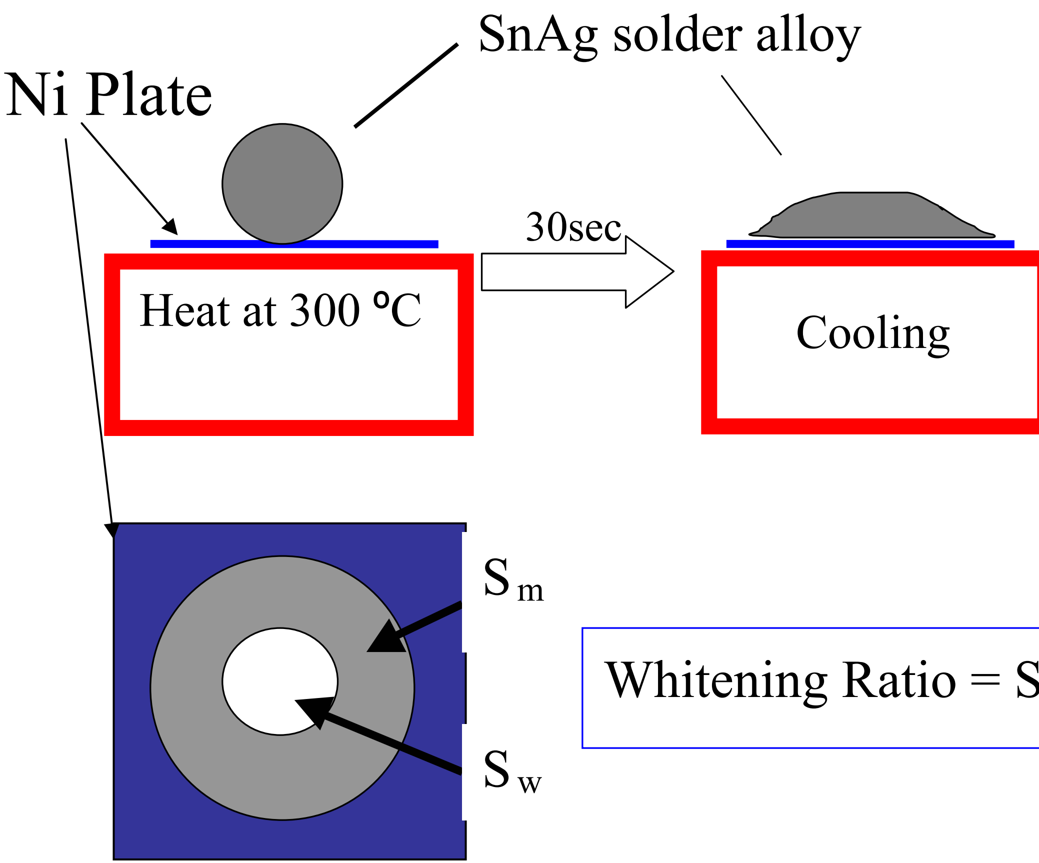


<Condition>

Alloy : SAC305

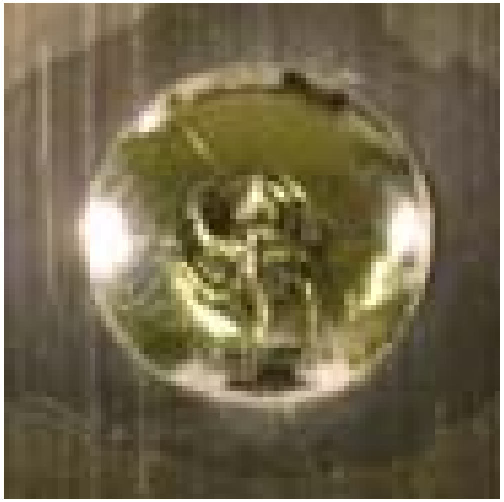
After 1000 Temp Cycle

2.8.3 Whitening Ratio Test Method



Whitening Ratio = S_w / S_m

2.8.4. Cooling Speed and Whitening Ratio

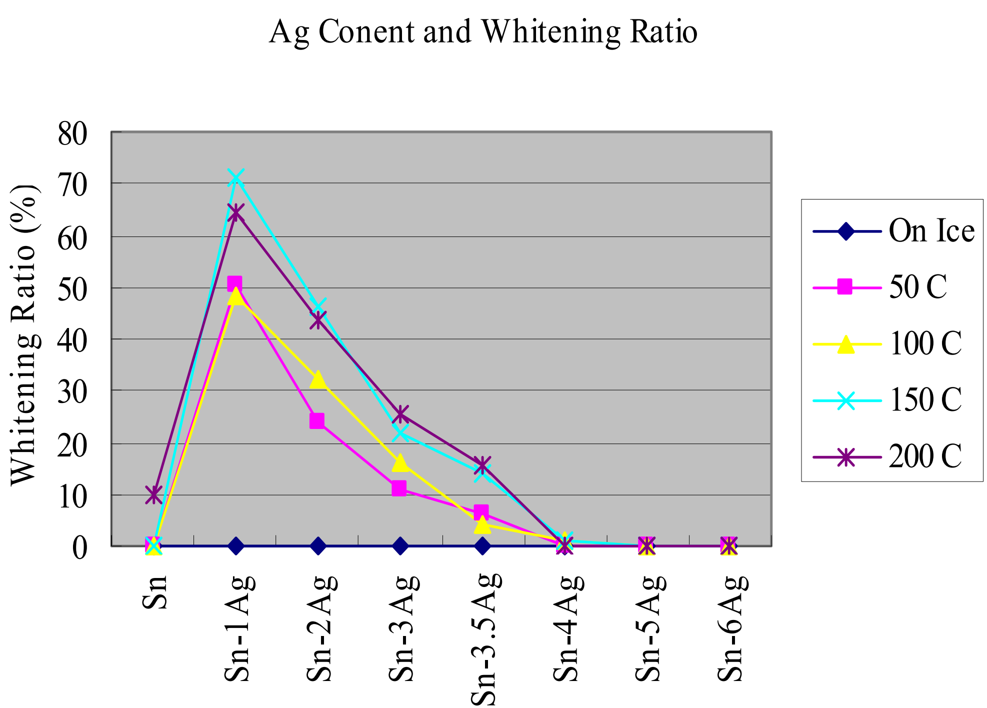


Solidify at 0 ºC

Solidify at 100 ºC

Solidify at 200 ºC

2.8.5 Whitening Ratio Test Results



Observations:

- Whitening most occurs at 1% Ag content solders, and gradually reduces to 0 at 4% Ag content.

- Faster cooling speed helps reduce the whitening, and no whitening is observed with cooling on ice.

3. Evaluation Points

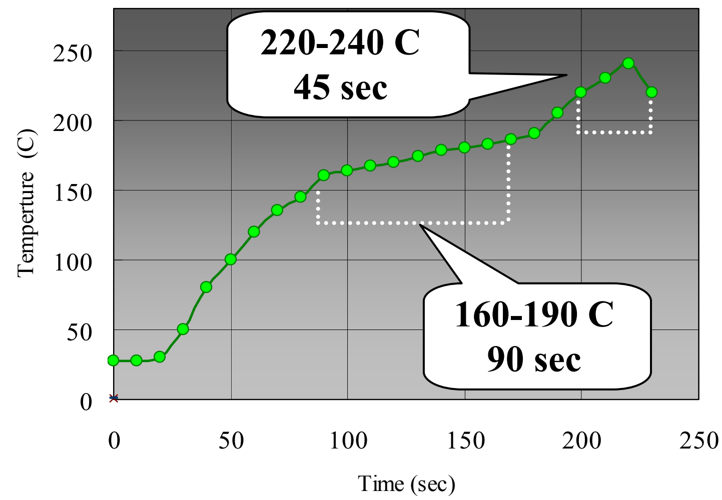
Test after 1,000 / 3,000 temperature cycles at -40 / +125 Deg C

1) **Shear Strength Test**
2) **Visual Analysis**
3) **Cross Section Analysis**
4) **EPMA Analysis**

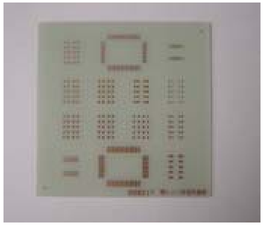
3. Test Specimen

Flux: Almit TM-HP (12% flux content)
PCB: Single sided glass epoxy 100 x 100 x 1.6mm
PCB Surface Finish: no plating (Cu land)

Component: 2125 Chip Condenser (Sn plated)
Reflow conditions: See chart / air atmosphere



Reflow Profile



Test Board

Component

Printer

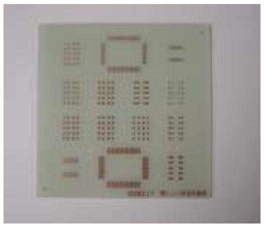
(Panasonic)

Chip Mounter

(i-PULSE)

Reflow Oven

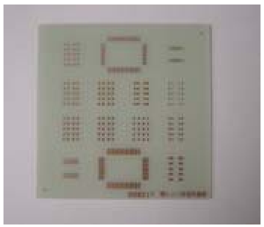
(Eighteck Tectron)



Test Specimen

3. Heat Cycle Testing

Heat Cycle Test



Specimen

Tester (Kato)

Temperature: - 40 / +125C

Transfer time: 20 Min

Dwell time: 30 Min

Test at initial / 1000 cycles

/ 3000 cycles

Shear strength test

Check impact on joint strength

Tacking Tester

(Aiko Engineering)

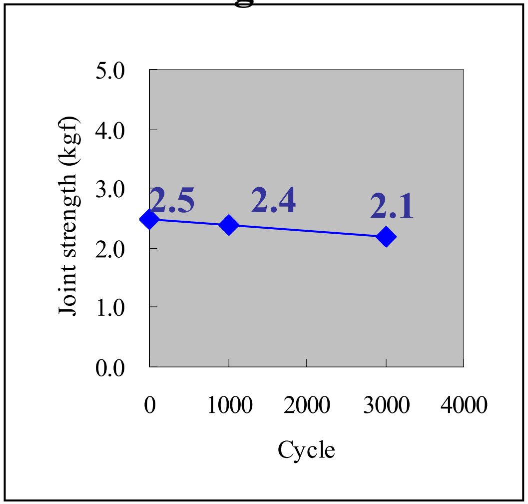
Cross section analysis

Check impact on molecule structure

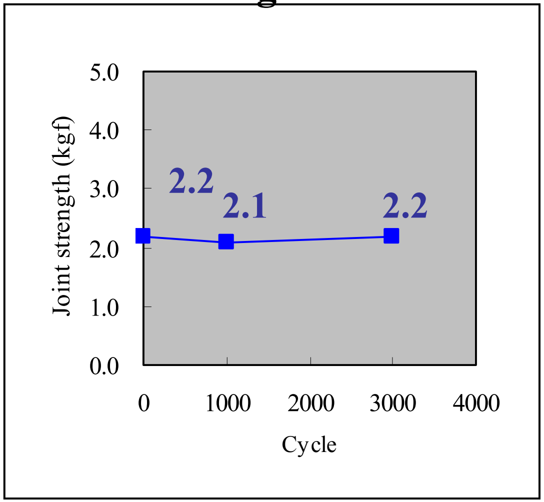
EPMA (JEOL)

3.1 Shear Testing

Sn-3.9Ag-0.6Cu



Sn-3.5Ag-0.7Cu



Speed: 12mm / min

Environment: 25 C

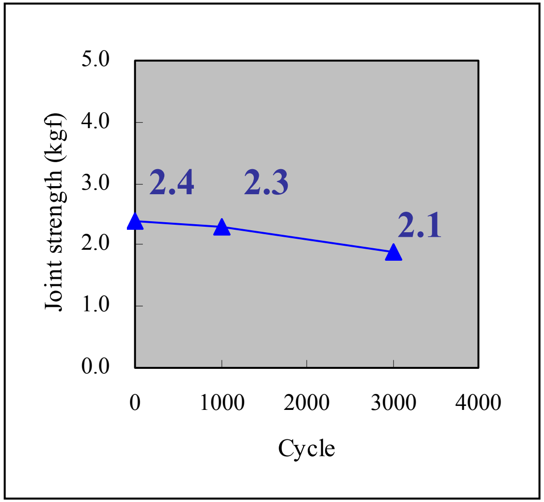
number of tests = 5

Initial / 1000 cycles: Break at component side (solder itself is intact)

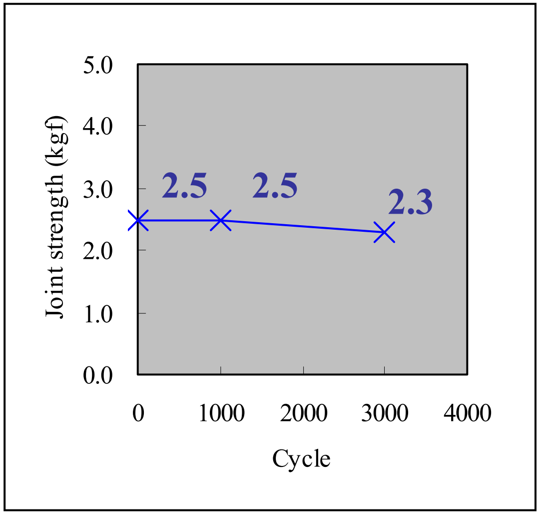
3000 cycles: Break at component and solder.

=> No significant variance among the alloys

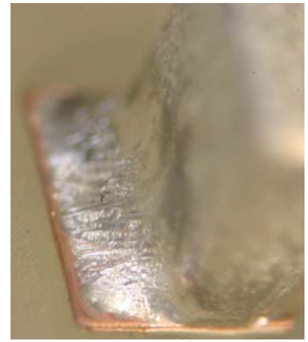
Sn-3.0Ag-0.5Cu



63Sn-37Pb



3.2. Visual Appearance

cycles	Sn-3.9Ag-0.6Cu	Sn-3.5Ag-0.5Cu	Sn-3.0Ag-0.5Cu	63Sn-37Pb
0				
1000				
3000				

3.2. Observation from Visual Appearance

- 0 cycles

All SAC alloys show a white streak (whitening phenomenon)

- 1000 cycles

Discoloration (not corrosion) of the flux is observed.

No surface changes or cracks observed.

- 3000 cycles

Wrinkles on the surface become more prominent.

No cracks observed.

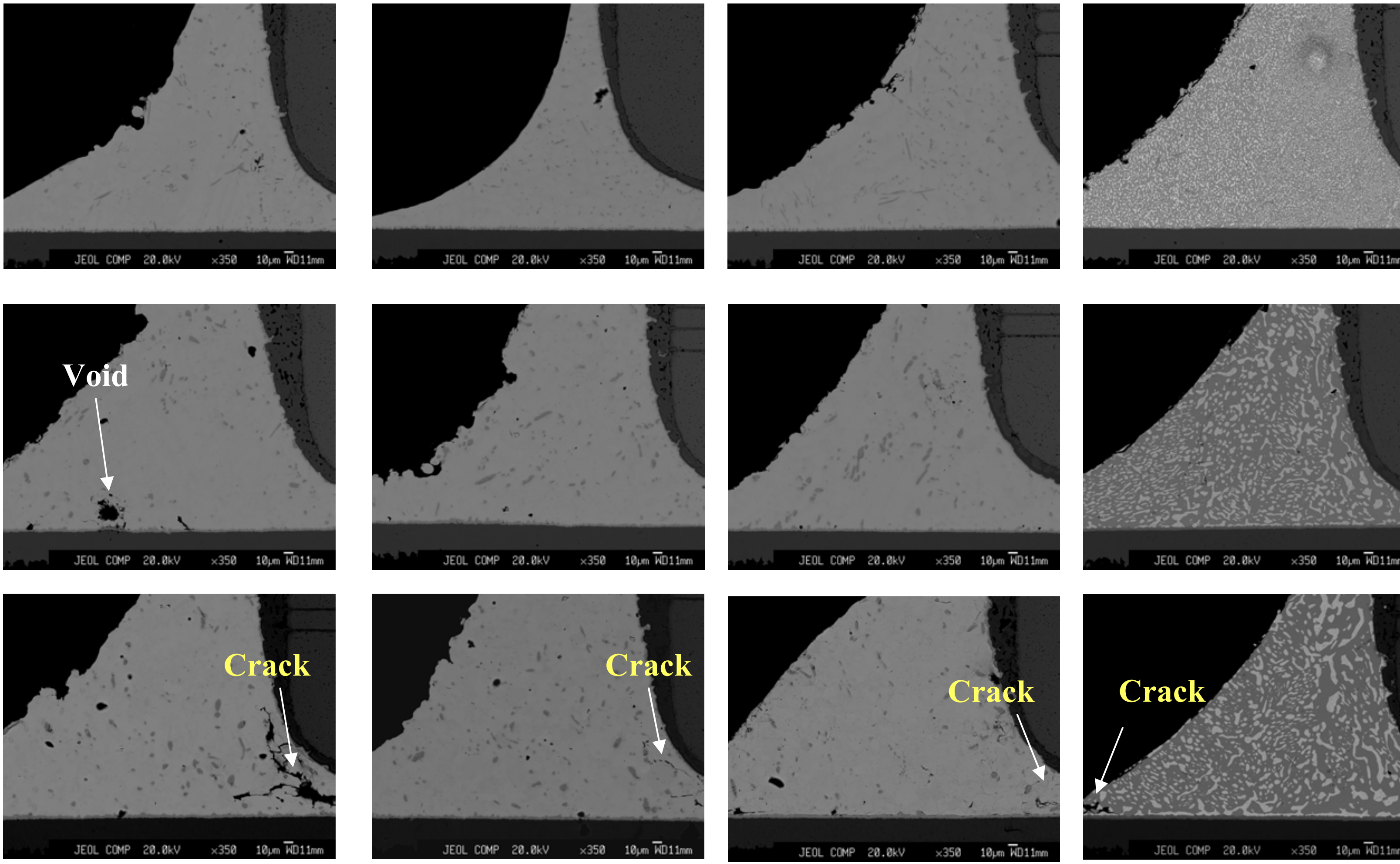
3.3.1 Cross Section Analysis (SEM x350)

Cycles | Sn-3.9Ag-0.6Cu | Sn-3.5Ag-0.5Cu | Sn-3.0Ag-0.5Cu | 63Sn-37Pb

0

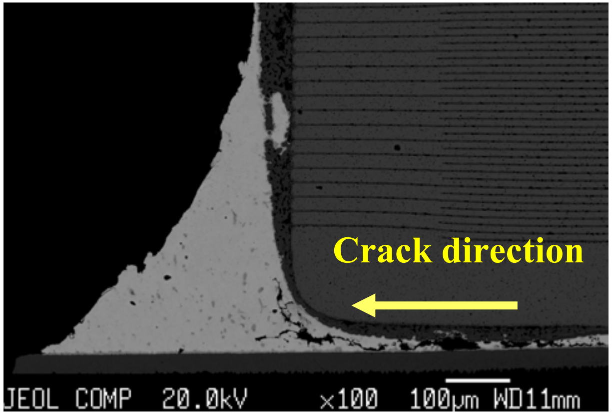
1000

3000

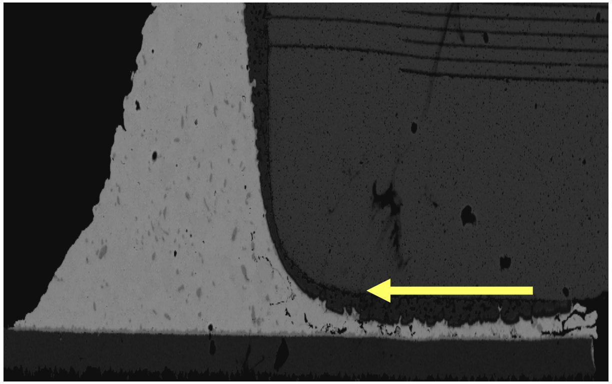


3.3.2 Crack Analysis @ 3000 cycles

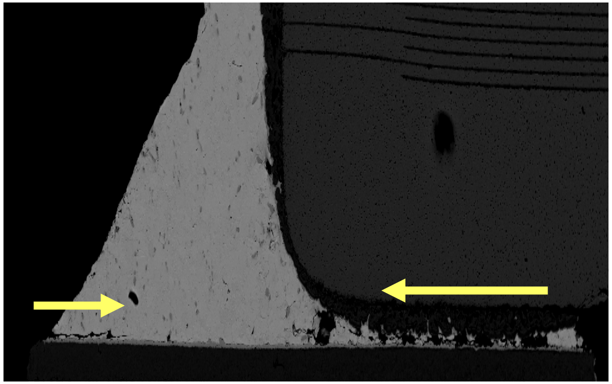
Sn-3.9Ag-0.6Cu



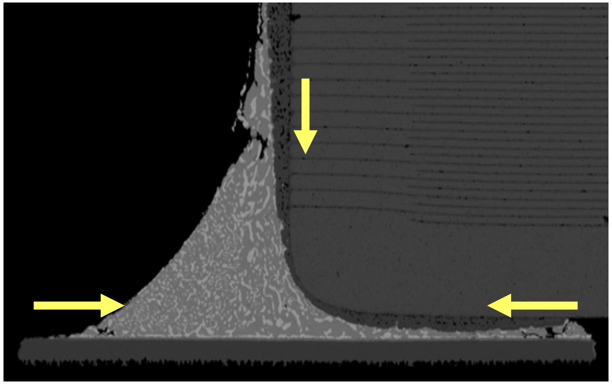
Sn-3.5Ag-0.7Cu



Sn-3.0Ag-0.5Cu



63Sn-37Pb



In all SAC alloys, cracks are coming in from under the component, which is normally considered the weakest point.

3.3.3 Observation from Cross Section

1000 cycles

SAC: Growth of inter-metallic layer thickness.
Growth of inter-metallic structure (Ag3Sn / Cu6Sn5 etc.) within the solder.
No noticeable difference
The void observed in SAC396 is not related to heat cycle

SnPb: Increase of grain size / Pb rich layer near inter-metallic layer.

Notes:

- Growth of inter-metallic layer is normally considered to weaken the joint strength.
- The inter-metallic structure / grain size change / is not at a level to affect the joint strength.
- Surface roughness is most likely due to the polishing for the cross section analysis.

3000 cycles

Cracks observed in all of the SAC and SnPb solders, primarily from under the component.

Further growth of inter-metallic layer thickness, inter-metallic structure observed.

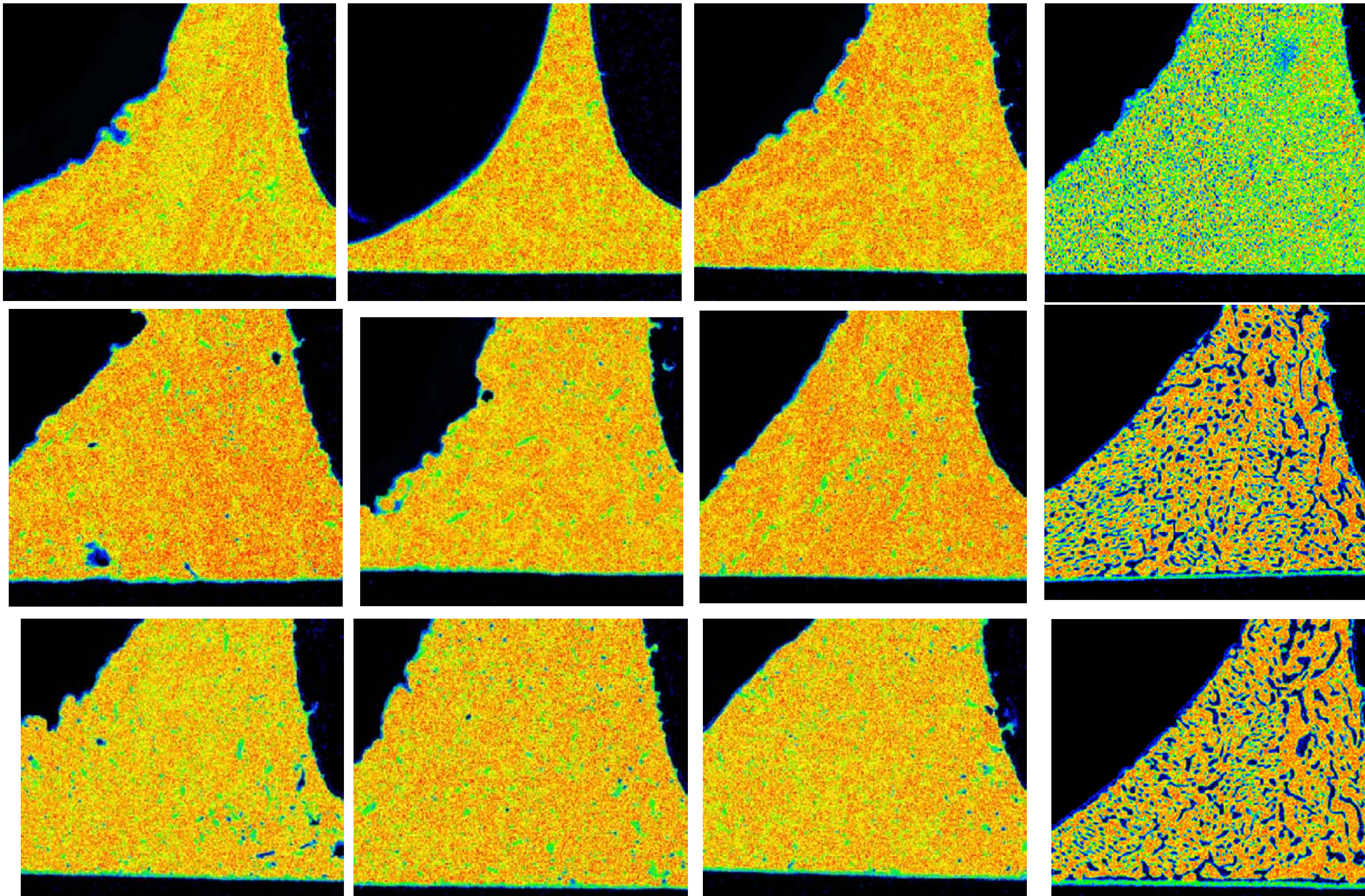
3.4.1 EPMA Analysis (Sn)

Cycles Sn-3.9Ag-0.6Cu Sn-3.5Ag-0.5Cu Sn-3.0Ag-0.5Cu 63Sn-37Pb

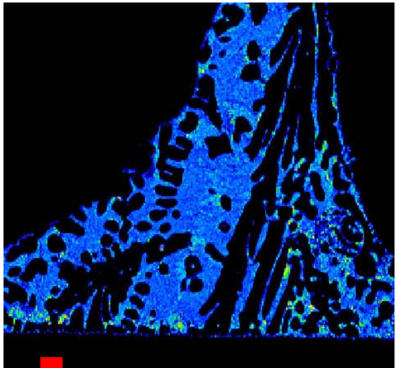
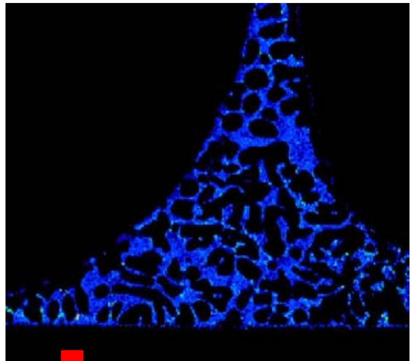
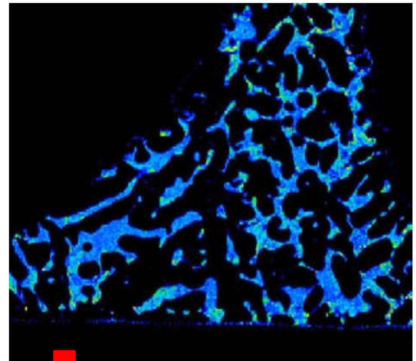
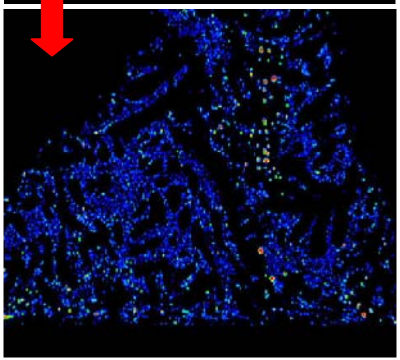
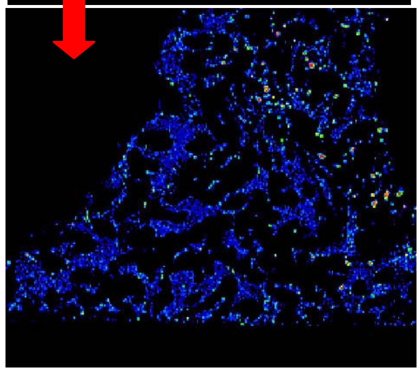
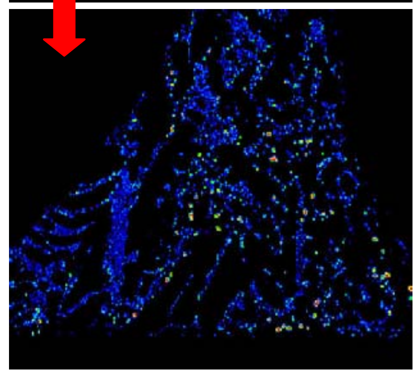
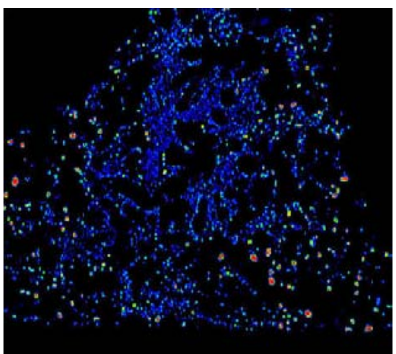
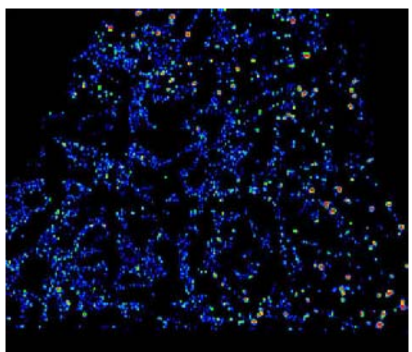
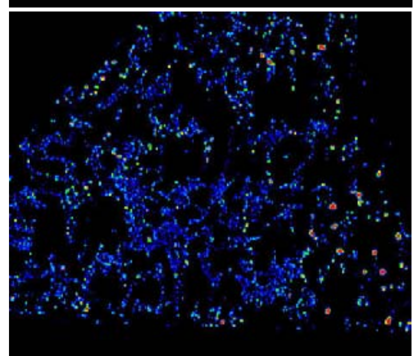
0

1000

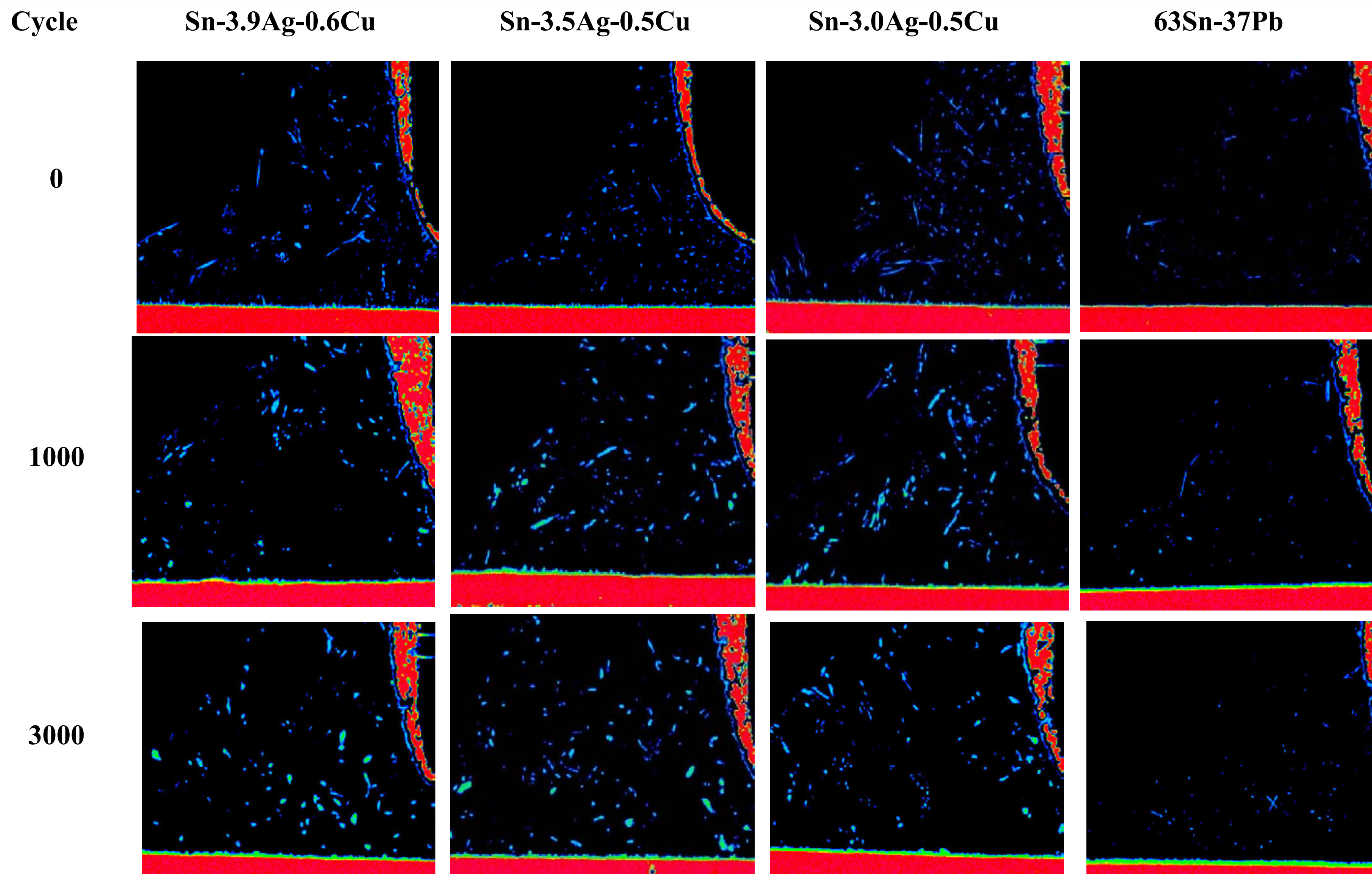
3000



3.4.2 EPMA Analysis (Ag)

Cycles	Sn-3.9Ag-0.6Cu	Sn-3.5Ag-0.5Cu	Sn-3.0Ag-0.5Cu	63Sn-37Pb
0				Not applicable
1000				Not applicable
3000				Not applicable

3.4.3 EPMA Analysis (Cu)



3.4.4 Observation from EPMA

<Sn>
- 1000 cycles

SAC: No significant change / SnPb: Increase of grain size
- 3000 cycles

No significant difference from 1000 cycles
=> No difference among the 3 SAC alloys/ SnPb: Further increase of grain size

<Ag=Ag3Sn>
- 1000 cycles

The network-like structure seen prior to heat cycling (Ag3Sn) has collapsed.
- 3000 cycles

The Ag(Ag3Sn) forms individual particles.
=> No difference among the 3 SAC alloys

<Cu>
- 1000 cycles

Growth of inter-metallic layer (Cu3Sn /Cu6Sn5) observed.
Growth of inter-metallic structure of Cu6Sn5 observed throughout the solder.
- 3000 cycles

Further growth of inter-metallic layer, and structure of Cu6Sn5.
=> No difference among the 3 SAC alloys

<Point>
Collapse of Ag (Ag3Sn) network-like structure is the most prominent from EPMA test.

4.1. Conclusion

- No significant difference has been observed among the 3 SAC alloys for mechanical properties.

- No significant difference has been observed among the 3 SAC alloys regarding joint strength or metallic structure after 3000 temperature cycles. (Cracks were observed in the solder, but effect on Joint "Shear" strength was minimal, and all alloys showed similar structure changes.)

- Higher Ag content material (Sn+3.9%Ag+0.6%Cu) will help reduce the occurrence of the whitening phenomenon, and will reduce the Hot-tear on the solder surface. The correlation of Hot-tear to reliability was not observed during this study (SMT), but depending on where the Hot-tear is located , it may possibly become an entry point for larger cracks in the solder surface.

<u>Points for alloy selection</u>

- Lower Ag content material will have the lowest price. (Sn+3.0%Ag+Cu0.5%)
- Higher Ag content material will help to reduce the whitening phenomenon occurrence (Sn+3.9%Ag+Cu0.6%) .

4.2 Other Comments

- The metal alloy itself is basically the same among solder manufacturers.

=> Flux will be the factor to differentiate good and bad solder products.

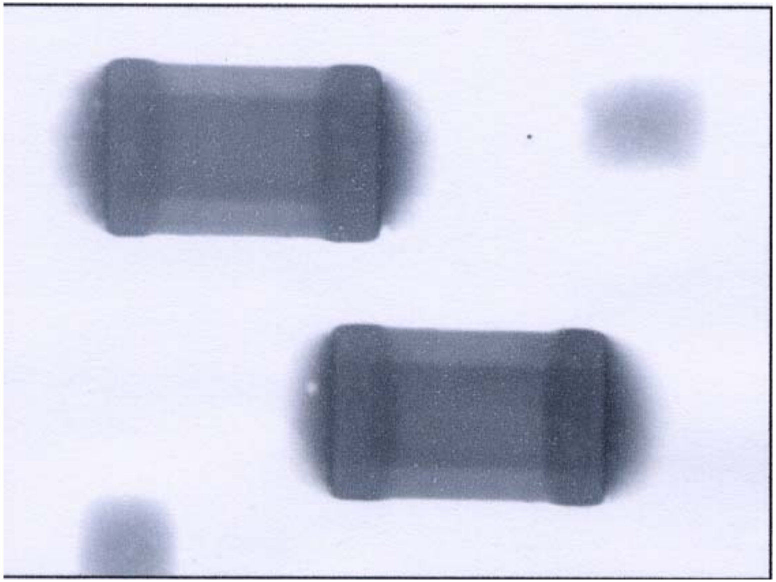
- Selection Points
- Cored Solder Wire: Spattering / Wetting
- Solder Paste: Printing / Wetting / Voids

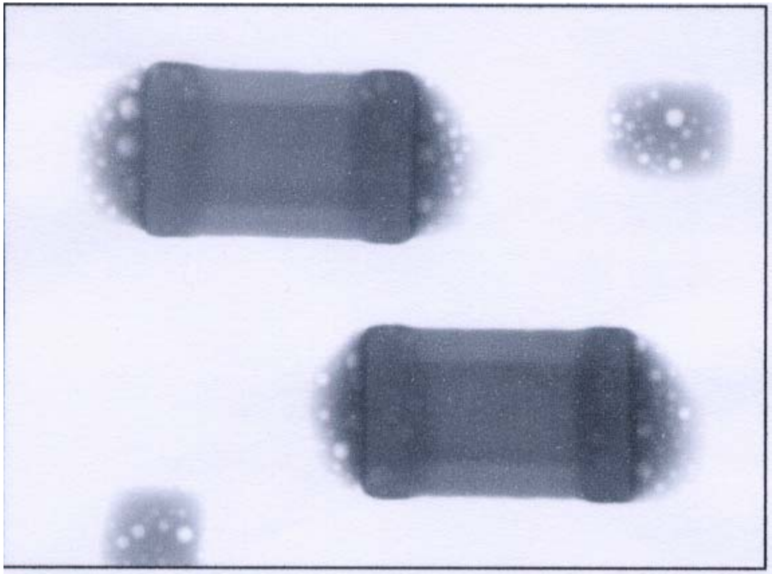
4.3.1 Flux Differences

Paste in good condition / paste in poor condition

Paste visual appearance after 24hours continuous printing. Paste on right is 'dry so powder oxidises heavily causing poor soldering.

Void results after reflow due to poor paste flux stability/powder oxidation.

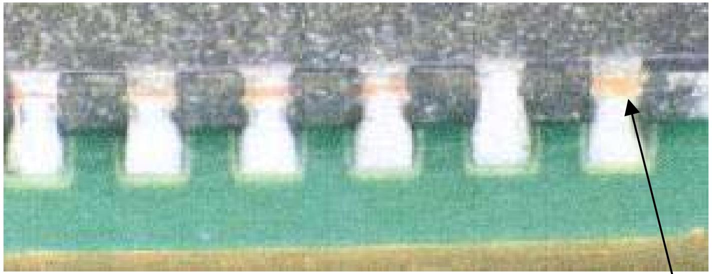




Good anti-voiding performance if paste flux is stable

4.3.2 Flux Differences

QFN Wetting Up



Exposed component termination = poor wetting.

Paste wettability. Solder on left has fully covered component termination but the paste on the right has not fully wet to component termination. This poor wetting will affect the solder joint reliability. Manufacturers must strive for the best wetting possible when using lead free solder as full pad/component termination wetting will indicate a reliable solder joint.

Thank You!

For any questions please contact

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